Energy, Mines and Resources Canada
Mineral and Energy Technology
CANMET
Mineral Technology Branch

Énergie, Mines et Ressources Canada
Technologie des Minéraux et de l'Énergie
CANMET
Direction de la technologie minérale

PHYSICAL METALLURGY RESEARCH LABORATORIES

CANMET

ANNUAL REPORT

FY 1986-87

PMRL 87-34 (TR)

PHYSICAL METALLURGY RESEARCH LABORATORIES

ANNUAL REPORT FY 1986-87

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135 pp

MICROMEDIA

PMRL 87-34 (TR)

CREW OF THE CANMET MOBILE FOUNDRY LABORATORY

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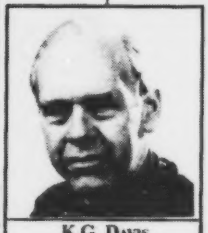

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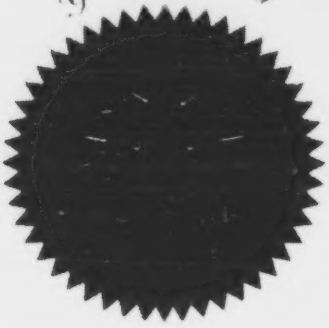

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CREW MEMBER

Merit Award

to

The CANMET Mobile Foundry Laboratory

for an exceptional
and distinguished contribution
to the effectiveness and efficiency
of the Public Service

M. SAHOO
TEAM LEADER

R.J. LACROIX
CREW MEMBER

ARTHUR KROEGER
DEPUTY MINISTER

Incentive Awards Canada / Primes d'encouragement Canada

R.D. WARDA
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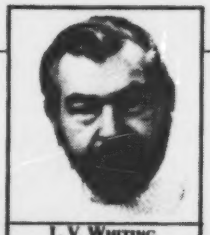

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FOREWORD

In an era when federal research laboratories are feeling the pressure of decreasing resources and, perhaps, are being under-rated as a national resource, it is a pleasure to preface this report by recalling a recent occasion when PMRL, acting in the public interest, used its expertise to the benefit of industry, i.e., by creating the Mobile Foundry Laboratory.

The Mobile Foundry Laboratory (MFL) was unique in concept and more visible to the public than others of our interactions with Canadian industry; it is nevertheless only one of many examples - albeit a spectacular one - of successful technology transfer. However, the opportunities to respond to national needs in this way abide in the scope of PMRL's facilities and expertise which underlie its claim to being Canada's national metals laboratory.

PMRL started the Mobile Foundry Laboratory (MFL) project during the severe economic downturn in the early part of the present decade. The objective was to provide immediate on-site technological support to a beleaguered Canadian foundry industry. Special funds, made available by the government, were used to purchase and equip a trailer with the tools for evaluating foundry process control and operating practices. Instrumentation on board the mobile laboratory included a direct reading spectrograph, sand testing equipment, metallographic facilities, and a computer together with the CANMET-developed software to analyze in-plant process control.

The mobile laboratory travelled coast-to-coast twice, visiting 76 of the approximately 250 foundries which operate in Canada. Following a two-day visit, every foundry received a confidential and timely report of the measurements and observations made during the visit, along with both short- and long-term recommendations designed to improve operations and increase their competitive position in the market place. A post audit of the project by an independent consultant showed the visits to be a resounding success. Over a five-year period, projected average savings attributable to the MFL project amounted to over $9 million for the 76 foundries visited at a benefit:cost ratio of 7:5.

Subsequently, operation of the project was transferred to the private sector through the auspices of the Association of Provincial Research Organizations, PMRL staff providing technical assistance as required.

Earlier this year, the 12 members of the foundry staff who ran the project so effectively were rewarded for their sustained effort and enthusiasm with Departmental merit awards.

W.H. ERICKSON
DIRECTOR

AVANT PROPOS

Alors que les laboratoires de recherche fédéraux souffrent de coupures budgétaires et qu'ils sont peut-être sous-estimés en tant que ressource nationale, il me fait plaisir de préfacer ce rapport en citant un cas récent où les laboratoires de recherche en métallurgie physique (LRMP) ont mis à contribution leur expertise au profit de l'industrie et dans l'intérêt du public. Je veux parler de la création du laboratoire mobile de fonderie (LMF).

Même si ce laboratoire était de conception unique et plus apparent que d'autres services que nous rendons à l'industrie canadienne, il n'est qu'un exemple entre autres - si exceptionnel soit-il - de transfert de technologie réussi. Toutefois, ces réponses à des besoins nationaux s'inscrivent dans le cadre des possibilités et de l'expertise des LRMP, ce qui leur permet de prétendre au titre de laboratoires métallurgiques nationaux.

Le projet de mise en service de ce laboratoire a été entrepris au creux de la dépression économique du début de cette décennie. Il visait à fournir, sans délai, un soutien technique sur le terrain, à l'industrie canadienne de la fonderie qui avait été durement éprouvée. Le gouvernement a alloué des fonds spéciaux pour l'achat du matériel et du fourgon qui a été doté de l'équipement requis pour faire l'évaluation des procédés et des méthodes de fonctionnement utilisés dans les fonderies. L'appareillage à bord du laboratoire mobile de fonderie comprend un spectrographe à lecture directe, de l'équipement d'essai de contrôle du sable, des installations métallographiques, un ordinateur et le logiciel développé par CANMET pour évaluer les procédés utilisés dans les installations.

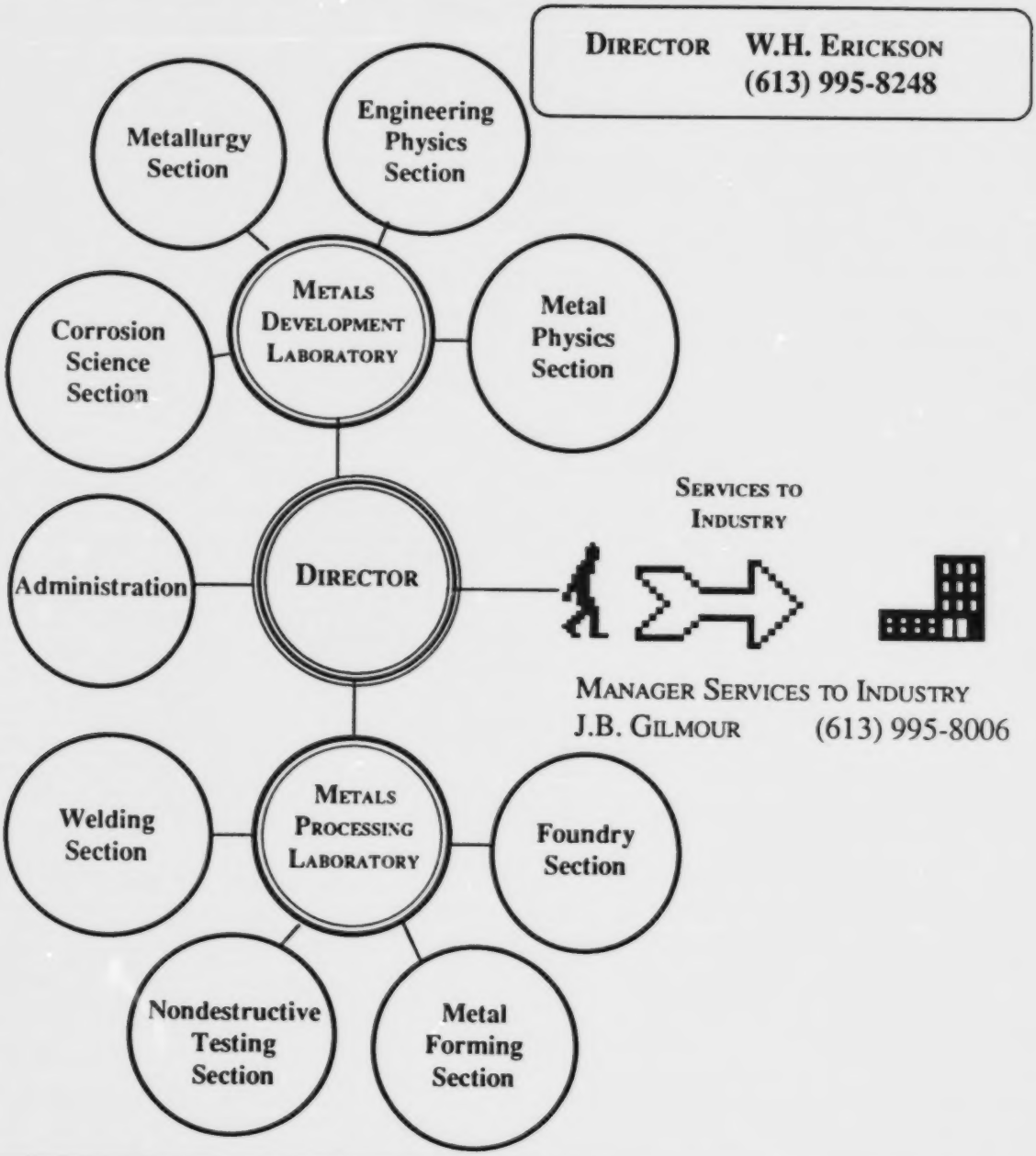
Le laboratoire mobile de fonderie a parcouru le pays à deux reprises, d'un océan à l'autre. Au total, il a rendu visite à 76 des 250 fonderies que compte le Canada. Le laboratoire a fait parvenir à chacune des fonderies visitées, un rapport confidentiel portant sur les mesures et observations faites pendant la visite. Ce rapport contient également des recommandations destinées à améliorer, à court et à long terme, les opérations des installations et à en accroître la compétitivité sur le marché. Une vérification financière du projet, effectuée par un expert-conseil indépendant au terme des visites, a démontré que celles-ci ont donné d'éclatants résultats. On prévoit que les économies que réaliseront les 76 fonderies visitées, au cours d'une période de cinq ans, atteindront en moyenne, plus de neuf millions de dollars, et ce, grâce aux visites du laboratoire mobile. Le rapport avantages - coûts prévu pour ce projet est de 7,5.

Les services du laboratoire mobile de fonderie ont depuis été transférés au secteur privé; l'Association des organismes de recherche provinciaux en assume la responsabilité et le personnel des LRMP en assure le soutien technique.

Les 12 membres du personnel de la fonderie qui sont les grands responsables du succès de l'entreprise se sont vus attribuer plus tôt cette année des récompenses de la part du ministère pour leurs efforts soutenus et enthousiastes.

W.H. ERICKSON
DIRECTOR

The Physical Metallurgy Research Laboratories (PMRL) have a staff of about 135. Of these about 55 are scientists or engineers and 50 are technical support staff. In addition, throughout the year PMRL has about 25 visiting staff composed of students, post-doctoral fellows and workers from industry. PMRL is divided into two laboratories of approximately equal size, the Metals Development Laboratory and the Metals Processing Laboratory. In turn each laboratory is divided into several sections.



Special Honours and Patents

Doug Boyd, Section Head, Metallurgy received the Dofasco Award for Materials Engineering "in recognition of outstanding contributions to the understanding and dissemination of knowledge in the field of composition, microstructure and mechanical property relationships in ferrous and non-ferrous alloys".

Mac Braid, Welding Section was awarded a busary by the Canadian Council of the International Institute of Welding to attend the 1986 Annual Assembly of IIW.

Graham Carpenter, Metal Physics Section was awarded a certificate of merit by the American Society for Metals "In recognition of an exceptional submission to the Metallographic Competition" of the Ontario Chapter, April 1986

The crew of the CANMET Mobile Foundry Laboratory: Don Brown, Bob Buhr, Earl Darke, Keith Davis, Bob Emmett, Henri-Paul Guindon, Richard Lacroix, Jean-Guy Magny, Rejean Matte, Mahi Sahoo, Dick Warda and Lawrence Whiting, Foundry Section received EMR Merit Awards for their outstanding contribution to the Public Service (see Foundry Section 5-1).

Dave Dolan and Russ Orr, Welding Section received EMR Sugestion Awards

Don Mak, Nondestructive Testing Section received the 1986 Technical Achievement Award from the Canadian Society for Nondestructive Testing for making "an outstanding contribution to nondestructive testing in Canada through technical achievement and technical publications."

Jean-Pierre Monchalin, Nondestructive Testing Section (IMRI) was awarded two patents:
"Laser heterodyne interferometric method and system for measuring ultrasonic displacements" US patent, Jan. 6th. 1987, No. 4 633 715.

"Optical interferometric reception of ultrasonic energy". US patent granted Sept. 25 1986.

Rod Packwood, Metal Physics was chosen as the "1986 Tour Speaker" for the Microbeam Analysis Society.

Mahi Sahoo, Foundry Section; Lawrence Whiting, Foundry Section; Vic Chartrand, Metal Physics Section and Gord Weatherall, Engineering Physics Section received the best paper award from the Brass and Bronze Division of the American Foundrymen's Society for 'Effect of strontium on the structure and mechanical properties of zinc-aluminum foundry alloys."

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METALS DEVELOPMENT LABORATORY

MANAGER D.W.G. WHITE 995-2828

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Corrosion Science Section

Section Head	R.W. Revie	992-1703

CORROSION SCIENCE SECTION

The overall objective of the Corrosion Science Section is to carry out research in cooperation with the private sector, to analyze, prevent, control, monitor and evaluate degradation by corrosion and by erosion. Research carried out during the past year in pursuit of these objectives is summarized in the following text.

MATERIALS FOR OIL AND GAS PRODUCTION AND TRANSPORTATION

CHARACTERIZATION OF STEELS FOR SOUR SERVICE

A 50/50 share-funded project with the Canadian Standards Association (CSA) Sour Service Task Force has been completed. Nineteen linepipe steels supplied by several companies were evaluated for their resistance to hydrogen-induced damage in H_2S-saturated buffered solutions.

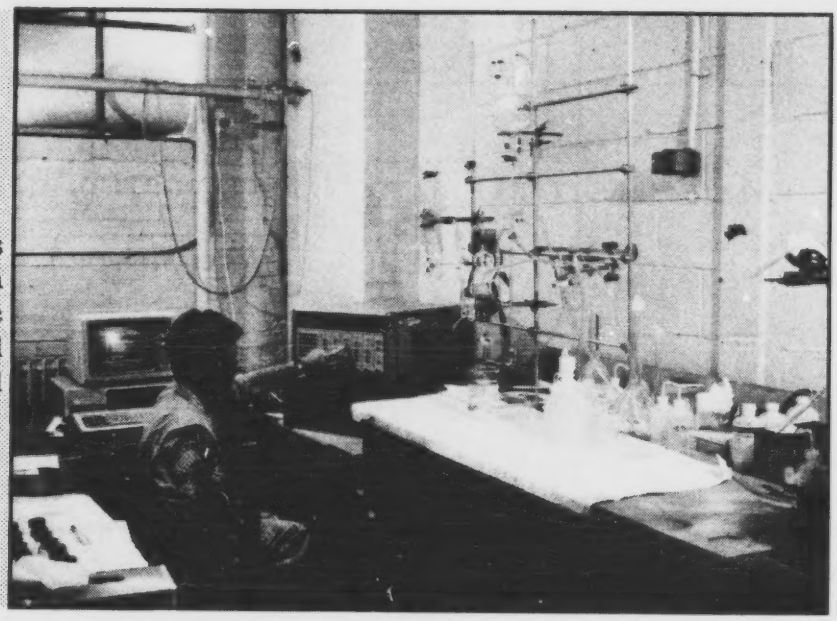
For each steel, the threshold hydrogen concentration (C_{th}) and threshold pH (pH_{th}) were determined. C_{th} is the minimum diffusible hydrogen which causes internal cracking of coupons when immersed for four days in an H_2S-saturated solution buffered at the threshold pH. Diffusible hydrogen in steel coupons was determined by the glycerol displacement method, and the presence or absence of cracking determined by ultrasonic C-scanning. Metallographic examination of charged steels showed that ultrasonic C-scanning is an effective method of detecting internal hydrogen cracking.

Diffusible hydrogen, for the 19 steels investigated, varied from 11.0 to 0.1 mL(STP)/100 g steel; C_{th} varied from 1.8 to 0.1 mL(STP)/100 g steel and pH_{th} from 4.0 to 5.9. In the temperature range 50°C to 12.5°C, C_{th} increased with decreasing temperature indicating a lower cracking susceptibility at lower temperatures. Conditions for immunity of line-pipe steels to cracking can be defined by C_{th} and pH_{th}.

An investigation is proceeding on a 50/50 share-funded project with the CSA Task Force to correlate cracking behaviour, C-scan results and microstructure of the steels.

HYDROGEN SULPHIDE INDUCED CRACKING OF ERW LINEPIPES

The cracking susceptibility of welds of electric-resistance welded (ERW) linepipes was investigated by a modified National Association of Corrosion Engineers (NACE) standard TM-02-84 test. Longitudinal weld coupons parallel to the pipe-rolling direction with and without surface flaws were exposed to H_2S-saturated synthetic sea water solution for four days. Diffusible hydrogen was determined at the end of each test followed by examination of the coupons for internal cracking by ultrasonic C-scanning. Cracking was not observed, and the diffusible hydrogen values also indicated very good resistance to cracking.



Corrosion measurements are carried out in a custom-made electrochemical cell under computer control

MATERIALS FOR COAL COMBUSTION TECHNOLOGIES

PERFORMANCE EVALUATION OF HEAT TRANSFER TUBE ALLOYS IN THE ENERGY, MINES AND RESOURCES - NOVA SCOTIA POWER CORPORATION FLUIDIZED-BED COMBUSTOR

One of the principal objectives of this EMR funded project was to provide long-term data on the corrosion behaviour of alloys used for in-bed combustors burning high-sulphur coal. Fluidized-bed combustion offers a means of burning coal to produce electricity while restricting the emission of SO_2 and

NO_x to within environmentally acceptable limits. The pilot plant, operated by the Nova Scotia Power Corporation, successfully completed a total experimental program of 11 000 h in 1985, and provided PMRL with over 800 specimens of ferritic and austenitic alloys exposed at temperatures from 450 to 850°C for periods of 1 000 to 10 000 h.

During 1986-87, the examination of all specimens was completed and the results analysed. All the alloys exposed exhibited a great variation in wastage rates from one region of the combustor to another, but analysis shows that excessively high wastage rates were the result of erosion, not corrosion. Nevertheless, it was possible to determine the relative performance of the alloys in the different temperature ranges of interest.

T91 was the only ferritic alloy to exhibit a promising performance and then only at temperatures below 550°C. Types 304H, 310 and 347H stainless steels were acceptable in most regions of the combustor at temperatures up to 700°C. At the temperature of the fluidized bed, 850°C, 310 and 347H exhibited similar, and acceptable, performance.

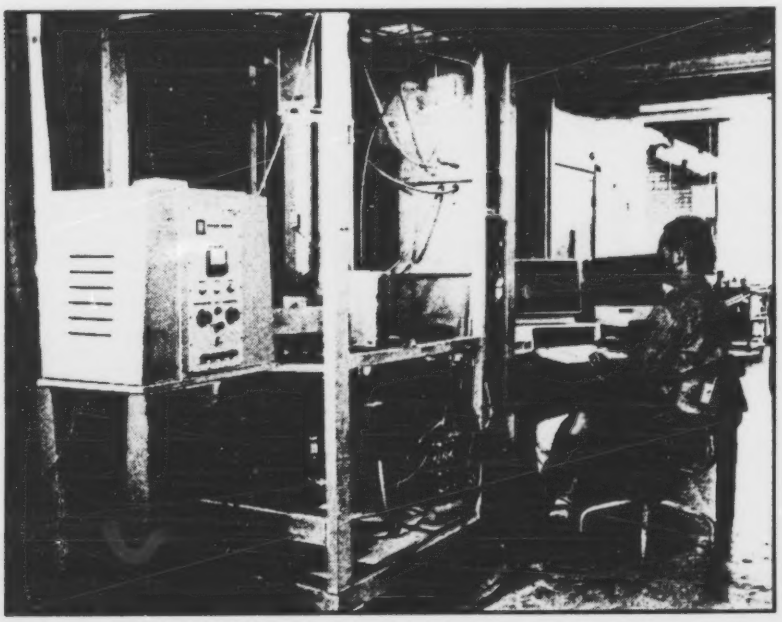
The Cr-Mo ferritic alloys formed iron oxide scales containing approximately the same Cr content as the alloy. With the exception of T91, which performed well, these alloys suffered high rates of attack from erosion. The cooled austenitic alloys suffered high wastage rates in some locations in the bed because of erosion. Internal sulphidation/oxidation attack also occurred although at rates which were not excessive for the better alloys. Attack of bed temperature probes occurred primarily as internal sulphidation/oxidation, and erosion was not important. Alloy 800H suffered catastrophic attack in several of the bed temperature probes.

The rate of erosion varied greatly from one location to another within the fluidized bed, with a trend toward higher rates on the samples located near the top. Although it is believed that high erosion rates were the result of high local velocities within the bed, it is not possible to state if a modified bed design would significantly decrease the rate of erosion. Nor is it possible to determine to what extent erosion was influenced by the physical and chemical properties of the feed-stocks.

The Point Tupper combustor used feed-stocks from one source only, because the project was not designed to evaluate feed-stock characteristics. Although it appears that corrosion of in-bed heat exchanger tubes will not limit the application of AFBC technology, erosion remains a problem. However, an economically useful solution to this problem probably lies in an improved understanding of bed dynamics and bed design rather than in the use of erosion-resistant alloys. Practical engineering solutions to combat erosion, such as protecting in bed tubes with studs, fins, baffles etc., are also promising.

EROSION CORROSION

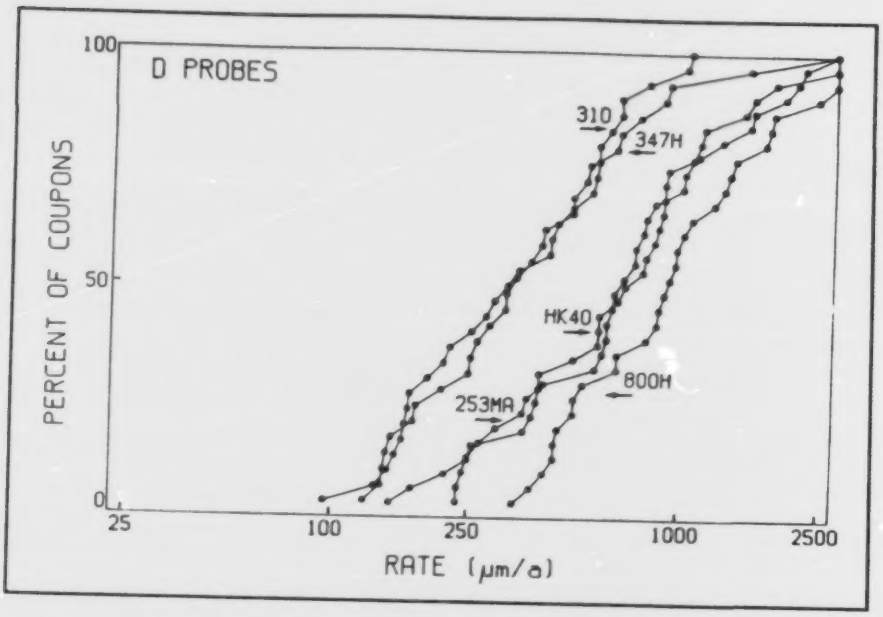
Erosion-corrosion testing apparatus was set up to study the wear behaviour of materials at temperatures up to 900°C and velocities of eroding gases up to 40 m/s. A corroding gas can have concentrations of SO_2 up to 0.5% and particulate loading rate as high as 20 g/min. The target material can present an angle of impact ranging from 15° to 90°. All operational conditions are controlled by microprocessor. The apparatus is now being used to study the effects of erosion-corrosion on the heat exchanger materials used in coal combustors.



Apparatus used to study erosion-corrosion under computer-controlled conditions of gas composition, gas flow rate and erodant velocity, as well as temperature between room temperature and 1 000°C

CORROSION MECHANISMS

A novel theoretical approach to initiating localized corrosion on stainless steels has been developed. As a result, the localized breakdown of passivity in high purity sulphate solutions has been predicted and subsequently confirmed on Type 410 stainless steel. Further research will be carried out.



Go/no-go temperatures for pit and crevice corrosion initiation on 410 SS in high purity 1M $Fe_2(SO_4)_3$ solution.

WELD-RELATED CORROSION OF HULLS OF ICE-BREAKING SHIPS

The objective of this work is to study the weld-related corrosion of ice-breaking ships.

An integrated program of in-house and contract research has proceeded on schedule. Results of electrochemical corrosion tests completed in the course of a cost-shared contract with a Canadian steel manufacturer correlate well with in-house free-corrosion tests. These data have been made available to industry. Complementary work in cooperation with the Canadian Coast Guard has produced confirmatory data related specifically to weld repair. It is now clear that a number of shielded-metal-arc and submerged-arc-welding consumables can be chosen to minimize or eliminate weld-metal corrosion, whereas the problem of heat-affected-zone attack can be controlled through modification of the steel-plate chemistry. Work is continuing in cooperation with the private sector.

ADVANCED MATERIALS

CORROSION CHARACTERISTICS OF RAPIDLY SOLIDFIED A1-FE BRONZES

Iron-aluminum bronzes are used in marine applications requiring a combination of high strength and corrosion resistance. Rapid solidification has been used as a means of refining the microstructure and increasing the solid solubility of Fe. An evaluation of the corrosion properties of these alloys by

potentiodynamic and free-corrosion measurements has demonstrated a significant improvement in the corrosion rate of rapidly- solidified alloys containing 3 to 8 wt % Fe. Heat treatment of the RS alloys at 800°C leads to precipitation of Fe-rich particles and an increased corrosion current. It is planned to study the corrosion characteristics of consolidated alloys in the next fiscal year.

INFLUENCE OF SURFACE MODIFICATION BY ION BEAMS ON ALLOY OXIDATION BEHAVIOUR

This research was carried out under contract to investigate the effectiveness of ion implantation and ion-beam mixing techniques in improving the high-temperature oxidation resistance of Fe-based alloys by increasing the aluminum concentration in the near-surface region. Samples ion-treated under various conditions were oxidized in oxygen at 0.1 MPa in the temperature range of 873 to 1373 K. The treated/oxidized specimens were analyzed by optical and scanning electron microscopy, Auger electron spectroscopy and Rutherford ion back-scattering. The ion treatments resulted in a beneficial effect on the oxidation resistance, the extent of which was dependent on the original alloy composition and temperature. Implanting aluminum in pure Fe is effective in decreasing the oxidation rate at 873 K, but ion-beam mixing is even more effective. Alloys implanted with Al show improved oxidation resistance at 1173 K, both in the rate of oxidation and in the morphology of scales. However, none of the treatments resulted in the formation of a continuous protective film of Al_2O_3, which would lead to a significant reduction in the oxidation rate.

LASER SURFACE TREATMENTS FOR IMPROVED HIGH TEMPERATURE CORROSION RESISTANCE

(in collaboration with the Division of Mechanical Engineering, NRC)

The effect of laser surface melting and alloying of commercial Fe-base alloys on high-temperature oxidation is being investigated. A 3 kW continuous-wave CO_2 laser is used in this investigation. The laser processing parameters needed to produce a modified layer 200 to 400 μm thick have been established.Direct surface melting produces a cored layer with large grains, which are roughly columnar in shape, and a heat-affected zone (~500 μm thick) significantly harder than the substrate. Surface melting after electroplating Cr produces a fully-adherent Cr-rich layer free of cracks and pores. The high temperature corrosion-erosion behaviour of these surface alloys is being evaluated in various atmospheres characteristic of fluidized-bed coal combustors.

CORROSION INHIBITION

XPS, Auger and electron microprobe analysis of mild steel samples exposed to chloride solutions containing molybdate, tungstate and chromate inhibitors showed that the inhibitor films formed at high pH values are more protective than films formed at low pH values. The molybdate film (monolayer) was $FeO.OH.MoO_3$, the tungstate film (monolayer) was Fe_2O_3 or $Fe_3O_4.WO_3$, the chromate film (many layers) was Fe_2O_3 or Fe_3O_4CrOOH.

SIMS ANALYSIS OF SURFACE-BOUND HYDROGEN IN STEELS

In work carried out under contract, quantitative measurements of hydrogen/deuterium in high-strength steels 1062, 4037 and 4140 made by Secondary Ion Mass Spectroscopy (SIMS) provided evidence for hydrogen/deuterium surface enrichment and a plausible hydrogen embrittlement mechanism.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Corrosion Science Section are underlined)

Brigham, R.J.
"Corrosion of welds in icebreaking ships"; Marine Engineering Digest; 6: 2; 29 1986.

Gilmour, J.B., Lui, A.W., Briggs, D.C., Knight, R.F, and Hindam, H.
"The Canadian atmospheric fluidized bed combustion materials program: Part I - Performance of alloys after 10 000 h. exposure; Corrosion 87; San Francisco , California; March 1987; NACE;
15-1; 1987.

Hindam, H, Gilmour, J.B, Packwood, R.H., Briggs, D.C., and Lui, A.W.
"The Canadian atmospheric fluidized bed combustion materials program: Part II - Metallographic Observations; Corrosion '87; San Francisco , California; March 1987; NACE;16-1; 1987.

Hoey, G.R., Ramsingh, R.R., and Bowker, J.T.
"Dependence of stress corrosion cracking of parent, heat-affected zone, and weld metal of HSLA line-pipe steel on potential"; Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods; Eds. G.C. Moran and P. Labine; American Society for Testing and Materials, Philadelphia, PA; ASTM STP 908; 386; 1986.

Mitrovic-Scepanovic, V., MacDougall, B., and Graham, M.J.
"The effect of Cl- ions on passivation of Fe-26Cr alloy"; Corrosion Science; 27:3; 239, 1987.

Sastri, V.S., Beauprie, R., and Desgagne, M.
"Molybdate as a pipeline corrosion inhibitant for coal-water slurry systems;" Materials Performance; 25: 6; 45; 1986.

Sastri, V.S., McIntyre, N.S., Johnston, D., Chauvin, W.J., Doern, F.E., Chan, T.C., McAlpine, E., and Lister, D.
"Analysis of corrosion and oxidation on metals by spectroscopic means"; Zeitschrift für Anal. Chem.; 324; 625; 1986.

Sastri, V.S., and Packwood, R.H.
"Surface analysis in corrosion inhibition mechanisms"; Werkstoffe und Korrosion; 38; 77; 1987.

AVAILABLE PMRL REPORTS

PMRL 86-1 (TR) Kinetics of localized corrosion of austenitic stainless steels. Part 1 Pitting in ferric chloride solutions. R. Brigham and E. Powers

PMRL 86-39 (TR) EMR/NSPC. AFBC materials program. Evaluation of the probe removed at the end of run 9. J.B. Gilmour, A. Lui, D. Brigg and R.F. Knight

PMRL 86-69 (TR) Kinetics of localized corrosion ofaustenitic stainless steel Part 2 - Crevice corrosion in ferric chloride solutions. E. Powers and R. Brigham

PMRL 86-68 (OP) Surface analysis in corrosion inhibition mechanisms. V.S. Sastri, R.H. Packwood and J.R. Brown

MRP/PMRL 84-19 (J) Studies on corrosion inhibition by some oxyanions in coal-water slurries. V.S. Sastri and J.S. Bednar

MRP/PMRL 85-48 (J) Review of the current status of the methods for the determination of hydrogen in steels V.S. Sastri

Effects of inclusions and segregation on stepwise cracking of line-pipe steels. M.J. Godden, G.J. Biefer, M.T. Shehata and J.D. Boyd	**PMRL 86-31 (OP-J)**
The slow strain rate technique for detemining sulphide stress cracking resistance of oil country tubular goods. G.R. Hoey R.R. Ramsingh and R.W. Revie	**PMRL 86-36 (J)**
Studies on the analysis of hydrogen in steels stored in various media. V.S. Sastri and C. Tjan	**PMRL 86-43 (J)**
Localized corrosion of stainless steel in high purity sulphate solutions. R. Brigham and V. Scepanovic	**PMRL 86-60 (J)**
Selected results after 5000 h exposure in the Canadian AFBC materials program. J.B. Gilmour, H. Hindam, A.W. Lui, D.C. Briggs and R.F. Knight	**PMRL 85-56 (OP-J)**
Corrosion of welds in icebreaking ships. R.J. Brigham	**PMRL 86-66 (OP-J)**
The Canadian atmospheric fluidized bed combustion materials program Part II: Metallographic Observations. H. Hindam, J.B. Gilmour, R. Packwood, D.C. Briggs and R. Knight.	**PMRL 86-74 (OP-J)**
The Canadian AFBC materials program. Part I: Performance of alloys after 10 000 h exposure. J.B. Gilmour, A.W. Lui and H. Hindam.	**PMRL 86-78 (OP-J)**

PRESENTATIONS

(Presenting authors from the Corrosion Science Section underlined)

Brigham, R.J.
"The CANMET weld-zone corrosion program"; CIM Conference of Metallurgists; Toronto, Ontario; August 1986.

Gilmour, J.B.
"Corrosion in an atmosphere fluidized bed combustor"; NACE Canadian Eastern Region Conference; Halifax, N.S.; Nov. 1986.

Gilmour, J.B., Lui, A.W., Briggs, D.C. Knight, R.F., Hindam, H.
"The Canadian AFBC materials program: Part 1- Performance of alloys after 10,000 hours exposure"; Corrosion/87; San Francisco, CA; March 1987.

Hindam, H., Gilmour J.B., Packwood, R.H., Briggs, D.C., and Lui, A.W. "Metallographic examination of candidate commercial alloys after one thousand hours exposure in an atmospheric fluidized bed coal combustor"; CIM Conference of Metallurgists; Toronto, Ont.; August 1986.

Hoey, G.R., Revie, R.W., Ramsingh, R.R., Mak, D.K., and Somerville, I.R. "Status report characterization of steels for sour service"; CSA Sour Service Task Force Meeting; Toronto, Ont.; Sept. 1986.

Mitrovic-Scepanovic, V.
"Effect of Cl ions on passivity of Fe-26 Cr alloy"; The Electrochemical Society 169th Meeting; Boston, Mass.; May 1986.

Revie, R.W., and Sastri, V.S.
"Corrosion prevention-inhibitors"; Corrosion and Corrosion Protection; Halifax, NS; June, 1986.

Sastri, V.S., Packwood, R.H., and Brown, J.R.
"Surface analysis in corrosion inhibition mechanisms"; Surface Canada '86; London, Ont.; June 1986.

Sastri, V.S.
"Corrosion inhibitors"; Workshop on "Corrosion"; Technical Univ. of Nova Scotia, Halifax, NS; June 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J.B. Gilmour	ORF	Evaluation of corrosion of FBC heat transfer tubes.
H. Hindam	Mc Master University	Effect of surface modification on alloy oxidation behaviour.
A. Lui	Mind-Machine Interface System	Maintenance of corrosion-erosion testor and documentation and modification of existing software.

SA/LO	Performer	Project
R.W. Revie	University of Manitoba	Evaluation of Al-Li-X ternary phase diagrams.
R.W. Revie	C&M Engineering	Effect of carbon dioxide on seamless and tubular goods.
V.S. Sastri	AMCA International Kanata, Ontario	Characterization and determination of surface-bound hydrogen in steels by secondary ion mass spectrometry (SIMS)

COMPLETED RESEARCH CONTRACT REPORTS

Evaluation of stress-rupture properties of stainless alloys in fluidized bed combustion environments.
Performer:
Scientific Authority D.C. Briggs

Evaluation of corrosion of FBC heat transfer tubes.
Performer: Ont. Research Foundation.
Scientific Authority J.B. Gilmour

Characterization and determination of surface bound H_2 and D_2 in 1062, 40274140 steels by secondary ion mass spectrometry.
Performer: AMCA International Ltd.
Scientific Authority V.S. Sastri

A study of the effect of surface modification on alloy oxidation behaviour.
Performer: McMaster Univ.
Scientific Authority H. Hindam

A study of sulfur solubility and diffusivity in Cr_2O_3 and its role in materials degradation in coal combustion systems.
Performer: Ecole polytechnique
Scientific Authority H. Hindam

Evaluation of weld zone corrosion of shipbuilding steel plates for use in the Arctic environment. Performer: Algoma Steel.
Scientific Authority R. Brigham

Engineering Physics Section

Section Head	W.R. Tyson	992-9573

ENGINEERING PHYSICS SECTION

The Engineering Physics Section is responsible for mechanical testing and fracture control. These encompass testing for tensile strength, hardness, impact toughness, and fatigue, as well as evaluation of fracture toughness by fracture mechanics methods and of residual stresses by experimental and analytical stress analysis. There is substantial research activity in corrosion fatigue, and contributions to fracture control by testing and consultation.

A complete range of equipment is available to perform conventional mechanical tests, and there is a specialized facility to pressurize pipe sections for studies of defect growth. In addition, members of the section have recently developed equipment to test the corrosion fatigue of heavy-section welded T joints, and to measure elastic-plastic toughness over a wide temperature range. Instrumented impact testing equipment exists to test Charpy-size samples as well as larger samples absorbing energies up to 13 kJ (pendulum machine) or 8 kJ (drop weight tower).

The Engineering Physics Section performs mechanical tests as a service to other sections as well as to industry, and participates with industry and with universities in projects that call for determining the mechanical behaviour of metals. To support this work, the section is developing competence in new test methods and is broadening the understanding of the factors controlling mechanical behaviour. Examples are the effects of thickness and temperature on fracture toughness and corrosion fatigue, and - a recurring theme - the effects of metallurgical microstructure on mechanical properties. In addition, considerable effort is devoted to stress analysis by analytical, numerical, and experimental methods, so as to properly interpret the effects of specimen geometry and processing history on the mechanical behaviour of materials.

The work of the section proceeds under the following five broad categories.

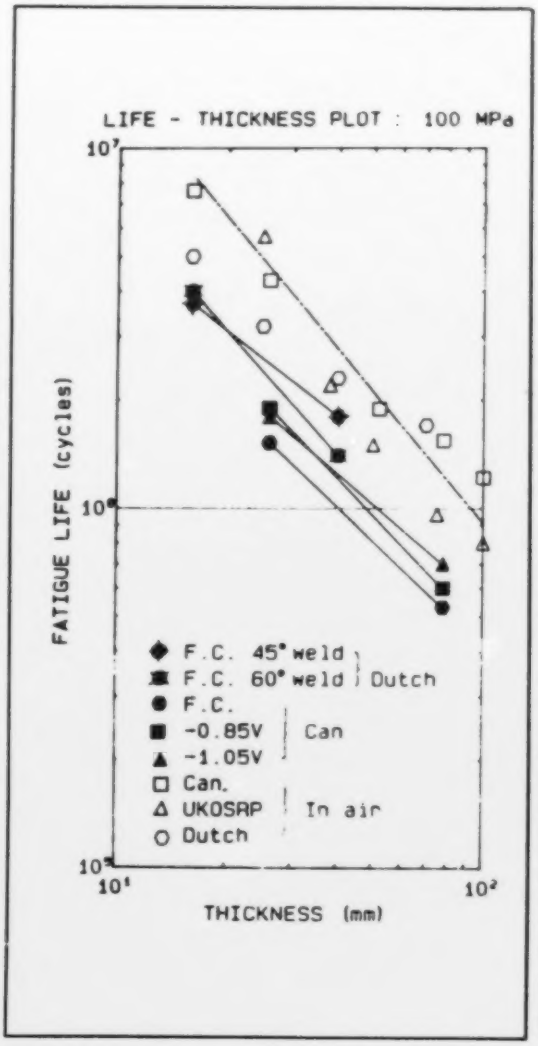
FATIGUE

Work has continued on evaluating the corrosion fatigue behaviour of welded joints representative of the welded joints of offshore structures. This work is complemented by contract research managed by AMCA International and information exchanges with the European Coal and Steel Community and Norway, giving access to North Sea offshore platform experience.

Important parameters which call for further study are section thickness, cathodic protection, ring stiffening of tubular joints, and random loading. The use of fracture mechanics in predicting the life of welded joints and in modelling tubular joints by much cheaper pipe-to-plate joints, is also an important aspect of the research.

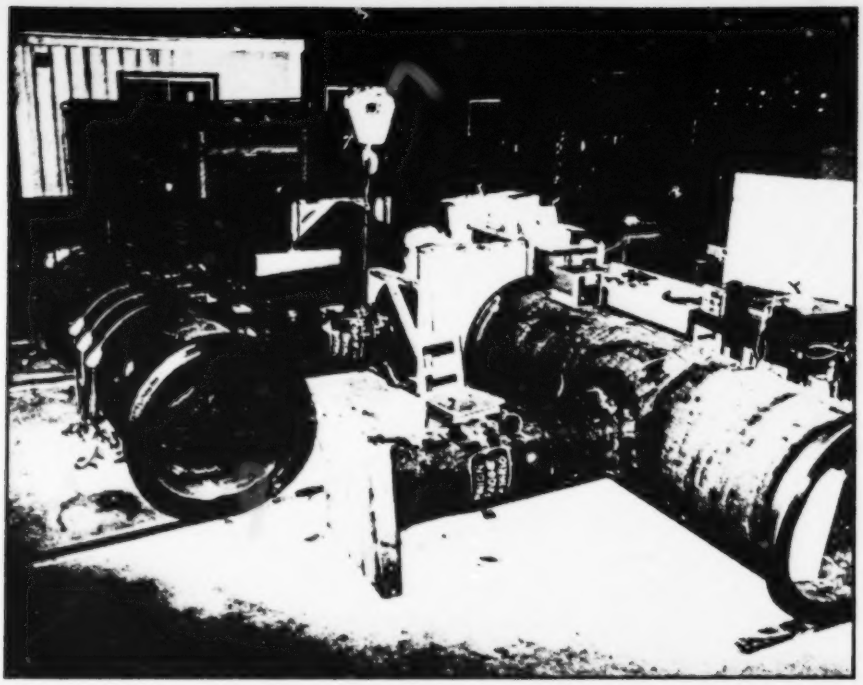
Studies of the effect of section thickness on the fatigue life of welded plate T-joints under constant amplitude loading in air and seawater have been completed. At constant hot-spot stress, both initiation and propagation lives are reduced as thickness increases.

Cathodic protection, either optimum or over-protection, provides little benefit in seawater corrosion fatigue of plate joints compared with free corrosion conditions. Some improvement was seen only at very long lives (above 106 cycles). The effect is probably associated with the plugging of cracks by calcareous deposits. An exhaustive review of all the data available from around the world of tests on plate and tubular joints supports these observations. Indeed, tubular joints do not show any benefit of cathodic protection even at long lives.



Reduction of fatigue life with increasing thickness at constant hot-spot stress. Data from Dutch and UKOSRP (United Kingdom) as well as Canadian programs. Note that cathodic protection at -0.85 V (optimum) or -1.05 V (over-protection) does not appreciably improve the fatigue life compared with free corrosion (F.C.) conditions.

Substantial progress has been made in applying fracture mechanics to fatigue crack growth predictions. Analytical models of multiple crack initiation and coalescence have been derived from experiments used in computer simulations of fatigue crack growth in plate joints. Equivalence of pipe-to-plate joints and tubular joints has been demonstrated; crack development is comparable in the two geometries up to crack depths of H85% of thickness. Corrosion life reduction factors indicated by models are in agreement with plate joint tests.



Large tubular joints awaiting testing.

Four tests (out of a total of 12) of tubular T-joints have been completed. Two reference joints (without stiffeners) and two internally ring-stiffened joints were tested by axial and in-plane bending fatigue loads. Tests indicate that effects of defects on the pressure at which pipes fail, and to set safety standards for pipes. Current work is focused on evaluating the effect of weld defects on the serviceability of electric-resistance-welded (ERW),(usually induction-welded) pipe. Major pipe manufacturers and pipe users participate in this project. Lengths of ERW pipe containing artificial and non-artificial defects are tested ultrasonically to measure defect sizes. Tensile samples of the weld regions are tested to measure the extent to which strength is reduced by ERW weld imperfections.

Data obtained at PMRL and elsewhere on the effects of dents and gouges on the pressure at which pipelines fail are being interpreted with the aid of empirical models and numerical stress analysis.

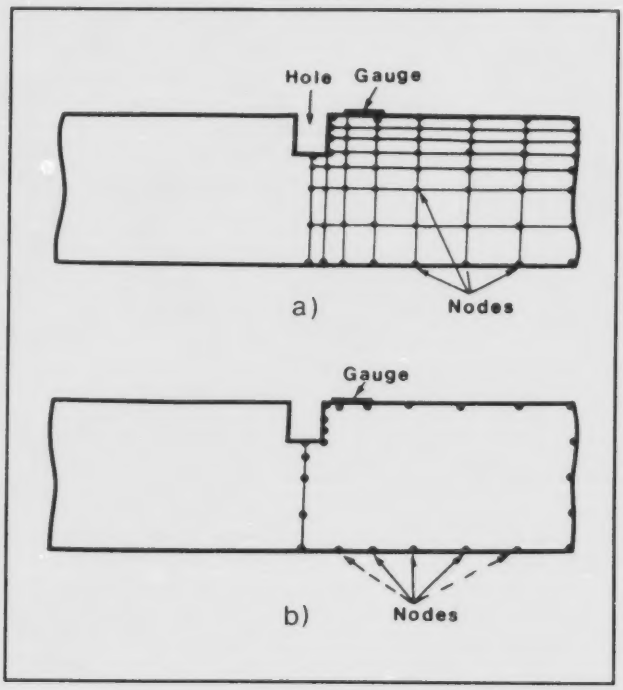
MECHANICAL TESTING

Much of the work done by the section is of a service nature to other sections within PMRL or to industry. The mechanical properties of new alloys are routinely evaluated. Tests are carried out on request, for example, to determine whether high pressure gas cylinders conform to Canadian Transport Commission specifications. During 1986/87, equipment for smooth-bar fatigue testing was refurbished to evaluate improved spring steels.

STRESSS ANALYSIS

To interpret mechanical test results (for example, the failure stress of a pipe containing a defect, or the fracture toughness of a welded joint) it is essential to be able to calculate and measure the stress pattern in a specimen. The section maintains expertise in experimental stress measurement by material removal techniques as well as in stress analysis by analytical and numerical methods.

The measurement and interpretation of residual stresses developed during welding is a continuing theme. Stresses in single-pass weldments have been measured by hole-drilling and X-ray and neutron diffraction measurements (the latter in collaboration with AECL). Comparisons with predictions of residual stress patterns calculated by finite element analysis performed under contract have shown good agreement.



Grids (node locations) used in numerical stress analysis around a drilled hole by: a) finite element and b) boundary element methods.

Preliminary work of a similar nature has been done on multi-pass welds. The insights gained are used to interpret residual stress patterns in large welded joints such as plate T-joints of offshore steels.

Preliminary results have also been obtained from numerical programs of finite element and boundary element methods modified to analyze mechanical denting of pipes.

FRACTURE CONTROL

Members of the section contribute to preventing structural failures in a number of ways: by performing failure analyses, by contributing to the writing of national codes and standards, and by testing structures containing known defects. For example, ship-plate failures are evaluated on request from Coast Guard Canada. Again, members of the Engineering Physics Section serve on a number of Canadian Standards Association (CSA) committees

concerned with the selection and use of steels for structures such as pipelines and offshore production platforms.

PMRL has a special purpose pressurization facility to determine the effects of defects on the pressure at which pipes fail, and to set safety standards for pipes. Current work is focused on evaluating the effect of weld defects on the serviceability of electric-resistance-welded (ERW),(usually induction-welded) pipe. Major pipe manufacturers and pipe users participate in this project. Lengths of ERW pipe containing artificial and non-artificial defects are tested ultrasonically to measure defect sizes. Tensile samples of the weld regions are tested to measure the extent to which strength is reduced by ERW weld imperfections.

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Preliminary work of a similar nature has been done on multipass welds. The insights gained are used to interpret residual stress patterns in large welded joints such as plate T-joints of offshore steels.

Preliminary results have also been obtained from numerical programs of finite element and boundary element methods modified to analyze mechanical denting of pipes.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Engineering Physics Section are underlined)

Bell, R., and Vosikovsky, O.
"3-D stress intensity factors for weld toe cracks and fatigue life prediction of plate T-joints"; 4th Irish Durability and Fracture Conference; Belfast, Ireland; Sept. 1986; 214; 1986.

Bhuyan, G.S., Arockiasamy, M. and Munoswamy, K.
"Three-dimensional stress analysis of tubular joint using rezone technique"; Canadian Journal of Civil Engineering; 13; 382; 1986.

Bhuyan, G.S., Arockiasamy, M., Munoswamy, K., and Vosikovsky, O.
"Finite element analysis of cracked and uncracked tubular T-joint"; Canadian Journal of Civil Engineering; 13; 261; 1986.

Faucher, B., and Tyson, W.R.
"Measurements of J. resistance curves with three-point-bend specimens"; The Mechanism of Fracture; Ed V.S. Goel; 2-6; Salt-Lake City, Utah; Dec. 1985; 205; 1986.

Krishnadev, M.R., Bouchard, R., Romhanyi, K. and Voyzelle, B.
"Fracture-microstructure-mechanical properties in an advanced HSLA steel"; Microstructure Science; 14; 1986.

AVAILABLE PMRL REPORTS

Dynamic properties of structural steels.(Interim report). K.C. Wang	**MRP/PMRL 85-3 (INT)**
Measurements of J-resistance curves withthree-point-bend specimens. B. Faucher and W. Tyson	**PMRL 85-64 (OP-J)**
Stress analysis by the method of superposition and collocation. G. Roy and W.R. Tyson	**PMRL 86-29 (OP-J)**
Further investigation on macro and micro characteristics of 2.25 Cr-1Mo steels with and without RE additions. H.Youshi, W.R.Tyson and M. Shehata	**PMRL 86-47 (OP-J)**
Dynamic fracture toughness of austempered ductile iron. B. Faucher K.C. Wang and M. Gagne	**PMRL 86-91 (OP-J)**
Evaluation of the fracture toughness of hot-rolled alloy Ti-V plate steel. B. Faucher and B. Dogan	**PMRL 86-62 (J)**

Three cost recovery reports was completed.by the Engineering Physics Section in FY 86/87.

PRESENTATIONS

(Presenting authors from the Engineering Physics Section underlined)

Bell, R.,and Vosikovsky, O.
"3-D stress intensity factors for weld toe cracks and fatigue life prediction of plate T-joints"; 4th Irish Durability and Fracture Conference; Belfast, Ireland; Sept. 1986.

Munaswany, K., Bhuyan, G.S., Swamidas, A.S.J. and Arokiasamy, M.
"Experimental and analytical studies on fatigue of stiffened and unstiffened tubular T-joints"; 18th Annual Offshore Technology Conference; Houston, Texas; May1986.

Roy, G., and Tyson, W.R.
"Stress analysis by the superposition and collocation method"; Symposium on Computer Modelling of Fabrication Processes and Constitutive Behaviour of Metals"; Ottawa, Ont.; May 1986.

Roy, G.
"Elasto-plastic analysis by the superposition and collocation Method"; 2nd Boundary Element Technology Conference, Betech 86; Massachusetts Institute of Technology, Boston, MA; June 1986.

Tyson, W.R.
"Toughness and section thickness effects of constraint and variability"; WIC Workshop on Steel Welding Research; Oakville, Ont.; April 1986.

Tyson, W.R.
"Initiation Control"; CFER Workshop on Toughness Requirements; Edmonton, Alberta; Feb.1987.

Tyson, W.R., Vosikovsky, O., Faucher, B. and Burns, D.
"Brittle fracture in heavy section welded T-joints"; ECSC/Canada Meeting; Halifax, N.S.; Sept. 1986.

Vosikovsky, O, and Tyson, W.R.
"Effects of cathodic protection on fatigue life of steel welded joints in seawater"; CANMET/CFER Workshop on Cathodic Protection; Dartmouth, N.S.; Sept. 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
G. Roy	R. Pick, University of Waterloo	Study on finite element modelling of multipass welds.
G. Roy	AMCA International Research and Technology Centre, Kanata	Distortion in panel welds Its numerical modelling and model verification.
G. Roy	Lloyd's Register of Shipping London, U.K.	Stress concentration factors for complex tubular joints.

SA/LO	Performer	Project
G. Roy	R. Pick, Univ. of Waterloo	Investigation of behaviour of weld residual stress in T-joint fatigue specimens.
W.R. Tyson	J. Provan, McGill Univ.	The reliability assessment of large cast steel castings.
W.R. Tyson	DnV, Calgary	Evaluation of fracture toughness data with respect to reliability of subarctic and arctic structures
W.R. Tyson	WIC Oaksville	Weldment toughness properties for arctic and offshore weldments.
W.R. Tyson	DnV, Calgary	Fracture control for arctic structures.
O. Vosikovsky	ARCTEC/Univ. of Waterloo	Offshore structures/ Fatigue evaluation of welded joints in a marine environment.
O. Vosikovsky	ARCTEC/Univ. of Waterloo, Memorial University of Newfoundland	Offshore structures/ Fatigue evaluation of stiffened tubular joints in a marine environment.
O. Vosikovsky	Carleton University	Offshore structures/ determination of stress intensity factors for weld toe defects: Phase III
O. Vosikovsky	Memorial University of Newfoundland	Offshore Structures/ Evaluation of relative effect of natural and synthetic seawater in corrosion fatigue.
O. Vosikovsky	The Welding Institute	Offshore Structures/ Fatigue performance of repaired tubular joints.

COMPLETED RESEARCH CONTRACT REPORTS

Study of finite element modelling of multipass welds
Performer: University of Waterloo.
Scientific Authority G. Roy

METAL PHYSICS SECTION

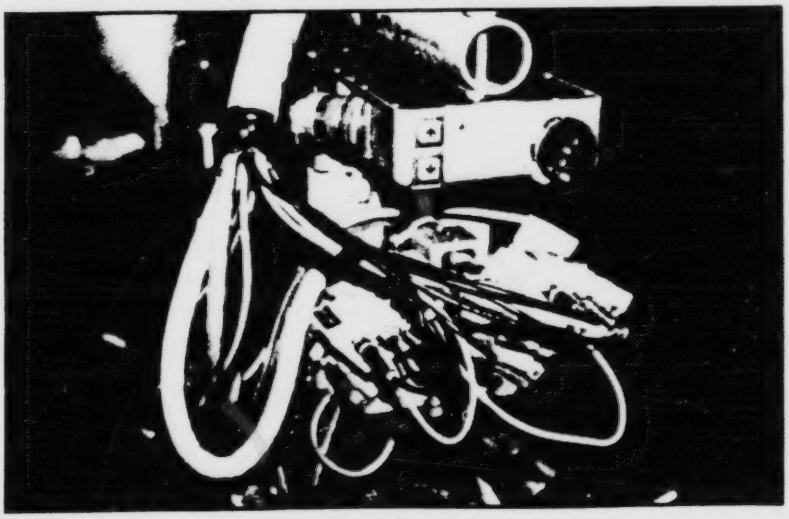
SECTION HEAD W.N. ROBERTS 992-8425

METAL PHYSICS SECTION

The primary objective of the Metal Physics Section is to perform research by X-ray and microbeam techniques on materials for PMRL, other government agencies, Canadian industry and the universities and to develop new methodology as necessary. The section has up-to-date X-ray diffraction, analytical electron microscopy, scanning electron microscopy, electron microprobe analysis and secondary ion mass spectrometry (summer 1987) facilities, for characterizing the microstructure and microchemistry of materials. The section has access to scanning Auger microscopy at the Energy Research Laboratories of CANMET.

X-RAY DIFFRACTION

A commercial prototype of the CANMET portable X-ray stress diffractometer has undergone successful field trials at Ontario Hydro and the Defence Research Establishment, Atlantic (DREA). The instrument was also used to measure surface stresses around welds in a deaerator tank at Ontario Hydro's Lakeview Generating Station. The tank had shown some evidence of stress corrosion cracking. To better observe the extent of cracking, the welded areas were sand-blasted. X-ray diffractometry showed that sufficient compressive stress was introduced by sand blasting to make minor crack propagation unlikely under normal service conditions.At DREA, stress measurements were made on a submarine hull in water. These measurements will be



The CANMET portable X-ray stress diffractometer shown measuring stresses in industrial piping.

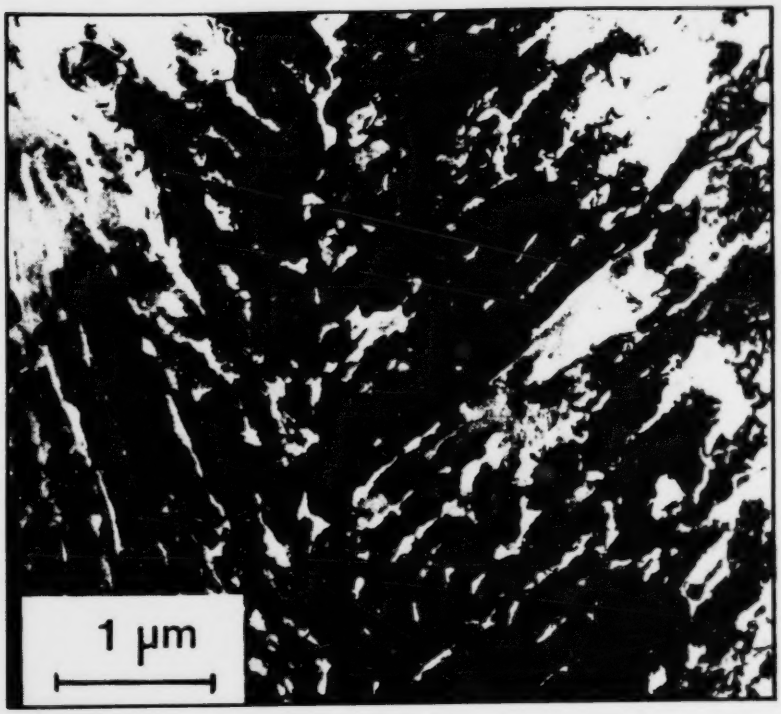
compared with those obtained by hole drilling at the same locations. The X-ray work was presented at a workshop on submarine fabrication in May 1987.Proto Manufacturing of Oldcastle, Ontario, after successfully manufacturing and testing a commercial prototype of the instrument, is making a second and improved version of the portable diffractometer for PMRL scheduled for delivery and acceptance testing in the summer of 1987.The experimental version of the stress diffractometer in the Metal Physics Section has been used to determine stresses in large-grained aluminum alloys, in single-pass welds in 316L stainless steel and in "T" welds in steels intended for offshore applications. Results from the last two investigations will be compared with stress measurements made by neutron diffraction at Chalk River Nuclear Laboratories.The construction of direct and inverse pole figures representing preferred orientation in materials with strong crystallographic texture has been automated by computer programs developed to plot data. A computer program obtained from Brigham Young University, Utah to calculate the orientation distribution function has been adapted to run on PMRL equipment. It gives correct results for random textures in cubic and hexagonal structures as well as for extrusion textures in hexagonal structures. It remains to be verified that the program runs correctly for real cubic textures.Studies have been made on texture in zirconium and titanium alloy extrusions; this work has considerable relevance to Canadian industry producing extrusions in these alloys for the nuclear and aerospace industries. Texture has also been measured in 316L welds and in the parent material. The purpose of this work was to explain an apparently low modulus in the weld metal and in the plate used in a "T" weld as well as to help interpret unambiguously the stress tensor from neutron strain data.

ANALYTICAL ELECTRON MICROSCOPY

The Laboratories' electron microscopy capability was given a boost by acquisition of a Hitachi H600 electron microscope from the recently disbanded Institute for Hydrogen Systems. The instrument was acquired with the support of CANMET's Mineral Science Laboratories and will be accessible to their staff. The new machine which replaces an ageing Philips EM300 has attachments for scanning transmission microscopy and energy dispersive X-ray analysis.

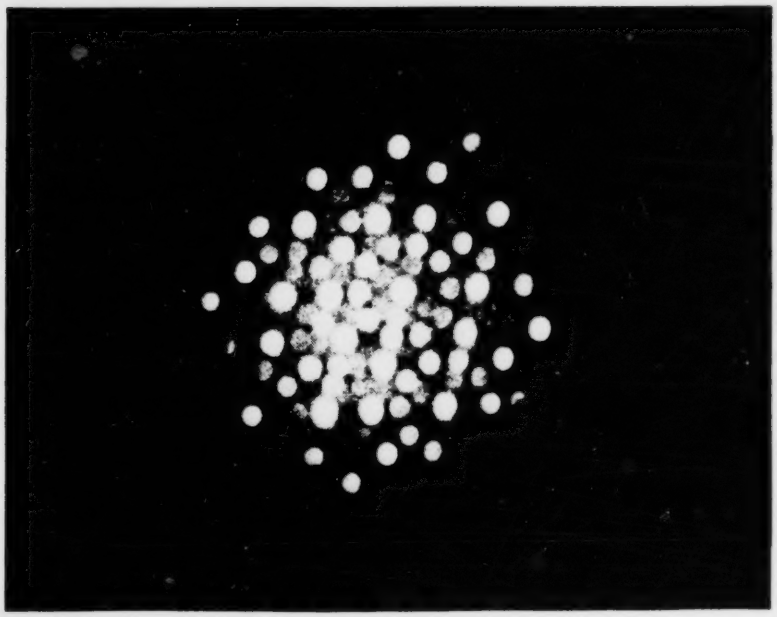
A number of improvements have been made in techniques for analytical electron microscopy. An approach first developed by E. Van Cappellen when at the University of Antwerp, Belgium, has been used to determine Cliff-Lorimer calibration factors for quantitative X-ray microanalysis in the electron microscope.

Computer programs have been written to analyze electron diffraction patterns. Electron energy loss spectrometry and convergent beam electron



Cored dendrites in a rapidly-solidified aluminum-magnesium silicon alloy.

diffraction are being used increasingly to identify phases. The figure above shows the microstructure of an A1-21 at %Mn-2 at %Si alloy, rapidly solidified by melt spinning. The micrograph shows cored dendrites, one of which the convergent beam electron diffraction pattern (below) shows it has 10-fold symmetry, characteristic of a quasicrystalline icosaedral phase.



Convergent beam electron diffraction pattern of a dendrite, showing the ten-fold symmetry of the quasicrystalline icosahedral phase.

Papers or reports have been published or written in the past year on such diverse topics as identification of zirconium hydrides by electron energy loss spectrometry, and studies by electron microscope of phase stability, decomposition and redistribution of intermetallic precipitates in Zircaloy -2 and -4 following neutron irradiation and the microstructural characterization of Cd_3As_2 films prepared by pulsed laser evaporation.

Electron energy loss spectrometry and X-ray microanalysis have been employed to characterize precipitates extracted from the heat-affected zone of weldments in Ti- and Nb- bearing steels for offshore structures. The microstructure of seamless tubing from a Canadian manufacturer, identified by transmission electron microscopy, pinpointed the cause of inadequate toughness properties which were subsequently alleviated by changes in heat treatment..

SCANNING ELECTRON MICROSCOPY AND ELECTRON MICROPROBE ANALYSIS

A Monte Carlo simulation has been run on a Cyber computer to predict f_o, the surface ionization as a function of incident electron energy (E_o) atomic number (Z) and specimen tilt. Computation times proved longer and hence, more expensive, than expected. Although this limited the size of the study, enough was accomplished to give a good idea of expected behaviour. Measurements of f_o were made for a small range of E_o, Z & tilt combinations, particularly at 0° tilt in the microprobe and H300 tilt in the SEM. Agreement between the Monte Carlo simulation and experiment and the theoretical predictions was very good with results that are at variance with commonly held views on the proper way to extrapolate from 0° specimen tilt (microprobe configuration) to about 30° specimen tilt (SEM configuration). A computer program has been written, to treat soft X-ray spectra in to yield quantitative analyses. The program accounts for background, self absorption, data smoothing, line positions, line shapes and intensities.

The use of Kossel patterns to determine crystallographic patterns of specimens in the scanning electron microscope has met with mixed success. Excellent back reflection Kossel patterns were obtained from large-grain iron specimens. However, specimens with small distorted grains, did not yield visible patterns, for reasons not known.

A number of specimens from copper refining anodes have been examined in the microprobe to identify inclusions. Element maps and print analyses were done on numerous specimens from the EMR-NSPC fluidized bed reactor at Point Tupper. The microprobe is well suited to the task of imaging micron-scale distributions of well-defined phases containing significant quantities of elements in the range of atomic number 12-30.

Scanning electron microscopy, usually in conjunction with X-ray energy dispersive analysis, has been used to examine coin blanks for the Royal Canadian Mint, Sundry railroad failures for the Canadian Transport Commission, the microstructures of bronze propellers for the Canadian Coast Guard as well as the microstructure of copper anodes and of rail steels, and the flaws n non-ferrous castings, fracture surfaces in numerous constructional steels.

SCANNING AUGER MICROSCOPY AND SECONDARY MASS SPECTROSCOPY

The scanning Auger electron microscope in the Energy Research Laboratories of CANMET is now fully operational after initial teething problems. An ion-gun has been put into operation and its operating characteristics have been studied so that it can be used knowledgeably to clean the surface of specimens before an Auger analysis is carried out. The instrument has been used to investigate surface segregation in rapidly-solidified alloys and their conventionally solidified counterparts as well as to study inclusions in steel, corrosion products in candidate alloys for fludized bed reactors and contaminants in semiconductors.

The CAMECA IMS-4f secondary ion microscope (SIMS) will be installed during the summer of 1987. The scientist responsible for the machine has spent a month at Arizona State University familiarizing herself with the instrument and some techniques for its use. She also spent time on a CAMECA IMS-3f SIMS at the University of Western Ontario - the only other installation of this type in Canada.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Metal Physics Section are underlined)

Brown, J.D. and Packwood, R.H.
"Quantitative electron probe microanalysis of small particles and thin films"; Applied Surface Science; 26; 294; 1986.

Causey, A.R., Fidleris, V. and Holt, R.A.
"Acceleration of creep and growth of annealed zircaloy-4 by pre-irradiation to high fluences"; J. Nucl. Mat.; 139; 227; 1986.

Galvani, C., Crawley, A., L'Esperance, G., Holt, R.A., and Cousineau, E.J.C.
"Precipation and textural effects in rapid annealing of cold-rolled aluminum killed steels"; Proc. 28th Mechanical Working and Steel Processing Conference; Pittsburg, PA; Oct. 1986; Iron and Steel Society of AIME; 287; 1986.

Holt, R.A.
"A comprehensive approach to in-situ stress measurement"; Advances in X-ray Analysis; 29; 29; 1986.

Holt, R.A., and Gilbert, R.W.
"<C> Component dislocations in annealed zircaloy irradiated at about 570 K"; J. of Nucl. Mat.; 137; 185; 1986.

Holt, R.A., Brauss, M., and Boag, J.
"In-situ stress measurement with the CANMET portable X-ray stress diffractometer"; 2nd International Conference on Non-Destructive Characterization of Materials; Montreal, Que.; July , 1986.

Jackman, J.A., Holden, T.M., Buyers, W.J.L., DuPlessis, P deV., Vogt, O., and Grenessor, J. "Systematic study of the lattice dynamics of uranium rocksalt structure compounds"; Physical Review; B33; 7144; 1986.

Jackman, J.A., Kim, S.M., and Buyers, Stott M.J.
"A temperature dependent angular correlation study of positron annihilation in single crystal zinc"; Journal of Physics F: Metal Physics; 16; 1319; 1986.

Packwood, R.H., Remon, G., and Brown, J.D.
"Electron microprobe analysis of compositionally stratified materials"; 11th International Congress on X-ray Optics and Microanalysis; Eds. J. Brown and R.H. Packwood; London, Ontario; Aug. 1986;.396; 1987.

Packwood, R.H.
"A general equation for predicting X-ray intensities from stratified samples in the electron microprobe"; Microbeam Analysis Society; Eds. A. Romig and W. Chambers; Albuquerque, New Mexico; August 1986; 268; 1986.

Parikh, N., Thompson, D.A., and Carpenter , G.J.C.
"Ion implantation in CdS."; Radiation Effects; 98; 289; 1986.

Sahoo, M., Whiting, L.V., Chartrand, V. and Weatherall, G.
"Effect of Strontium on the structure and mechanical properties of zinc-aluminum foundry alloys";Transactions of the American Foundrymen's Society; 94; 225 1986.

Woo, O.T., and Carpenter, G.J.C.
"Identification of zirconium hydrides by electron energy loss spectroscopy "; Scripta Met; 20; 423; 1986.

Woo, O.T., and Carpenter, G.J.C.
"Identification of Zr and Ti hydrides by EELS"; 11th Int. Conf. on X-Ray Optics and Microanalysis; Eds. J. Brown and R.H. Packwood; London, Ontario; Aug. 1986;.396; 1987.

AVAILABLE PMRL REPORTS

Assessment of the application of the CANMET stress diffractometer to suspensions of ceramics and metal in plastics. R.A. Holt and E.J. Cousineau	**PMRL 86-45 (INT)**
A general equation for predicting X-ray intensities from stratified samples in the electron microprobe. R.H. Packwood	**PMRL 86-10 (OP-J)**
In-situ stress measurement with the CANMET portable X-ray stress diffractometer. R.A. Holt, M. Brauss and J. Boag	**PMRL 86-59 (OP-J)**
Electron probe microanalyses of compositionally stratified materials. R.H. Packwood and G. Remond	**PMRL 86-63 (OP-J)**
Surface analysis in corrosion inhibition mechanisms. V.S. Sastri, R.H. Packwood and J.R. Brown	**PMRL 86-68 (OP)**
The Canadian atmospheric fluidized bed combustion materials program Part II: Metallographic observations. H. Hindam, J.B. Gilmour, R. Packwood, D.C. Briggs and A. Lui	**PMRL 86-74 (OP-J)**

Four cost recovery reports were completed by the Metal Physics Section in FY 86/87.

PRESENTATIONS

(Presenting authors from the Metal Physics Section underlined)

Carpenter, G.J.C.
"Transmission electron microscopy of materials"; ASM Course on Materials; PMRL/CANMET, Ottawa, Ont.; April 1986.

Carpenter, G.J.C.
"Modern techniques of transmission electron microscopy"; Algonquin College, Ottawa, Ont.; Feb.1987.

Carpenter, G.J.C., Cherns, D. and Mallard, R.
"On the existence of MCP silicon in poly-silicon"; 36th Canadian Metal Physics Conference; RMC, Kingston, Ont.; June 1986

Carpenter, G.J.C.
"Applications of analytical electron microscopy in materials research"; Chalk River Nuclear Labs., Ontario; Feb.1987.

Galvani, C., L'Esperance, G., Crawley, A., Holt, R., and Cousineau, E.
"Precipitation and textural effects in rapid annealing of cold rolled Al-killed sheet"; Canadian Metal Physics, Kingston, Ont.,June 1986.

Gundjian, A., and Badaye, M., Holt, R.A., Cousineau, E.J.C.
"Crystallographic texture of vacuum deposited tellurium films"; Canadian Metal Physics Conference, Kingston, Ontario; June 1986

Hindam, H., Gilmour, J.B., Packwood, R.H., Briggs, D., and Lui, A.
"Metallographic examination of candidate commercial alloys after several thousand hours exposure in an atmospheric fluidized-bed coal combustor"; C.I.M.Cof. of Metallurgists; Toronto, Ont.; Aug. 1986.

Holt, R.A. and Aldridge, S.A.
"Simultaneous multiple pole figure determination in Ti-6% Al-4%V extrusions"; Canadian Metal Physics Conference; Kingston, Ontario;June 1986.

Holt, R.A., Brauss, M., and Boag, J.
"In-situ stress measurement with the CANMET portable X-ray stress diffractometer"; 2nd International Symposium on Non-Destructive Characterization of Materials, Montreal, Quebec, July 1986.

Holt, R., Gundjian, A., Badaye, M., and Cousineau, E.
"Crystallographic texture of vacuum deposited Te films"; Canadian Metal Physics; Kingston; June 1986.

Jackman, J.A.
"Experiences in secondary ion mass spectrometry at Arizona State University"; PMRL/CANMET Ottawa, Ont.; Dec. 1987.

Packwood, R.H.
"Microprobe analysis from semi-infinite to sub-monolayer specimens"; Dearborn, MI;Denver, CO; Palo Alto, CA; Pasadena, CA; May 1986.

Packwood, R.H., Parker, C., and Moore, V.E.
"Physics and chemistry in soft X-rays"; (Poster Presentation) 11th International Congress on X-ray Optics and Microanalysis; U.W.O. London, Ont.; August 1986.

Sastri, V., Packwood, R.H., and Brown, J.R.
"Surface analysis in corrosion inhibition mechanisms"; U.W.O. London, Ont.; June 1986.

Woo, O.T., and Carpenter, G.J.C.
"Identification of Zr and Ti hydrides by electron energy loss spectroscopy"; 36th Canadian Metal Physics Conference; RMC, Kingston, Ont.; June 1986

Woo, O.T., Carpenter, G.J.C., MacEwen, S.R. and Parker, J.D.
"Zr-Fe intermetallic particles in Zr-2.5% Nb"; 36th Canadian Metal Physics Conference; RMC, Kingston, Ont.; June 1986

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
G.J.C. Carpenter	Prof. S. Saimoto Queen's University	A. determination of preferred grain boundary precipitation instainless steels to facilitate design of thermo-mechanical processing.

SA/LO	Performer	Project
G.J.C. Carpenter	Prof. G.R. Piercy McMaster University	Microstructive of Compound Semiconductor Devices
G.J.C. Carpenter	Dr. M.A. Clark Ont. Hydro Research	In-situ metallographic examination of ferrous and non-ferrous components."
R.A. Holt	Proto Manufacturing Ltd., Oldcastle (near Windsor, Ont.)	CANMET X-ray stress diffractometer
R.A. Holt	Itres Research Ltd. Calgary, Alta.	Prototype position-sensitive X-ray detector

METALLURGY SECTION

SECTION HEAD J.D. BOYD 992-6674

METALLURGY SECTION

Materials technology is in the midst of momentous change. Traditional materials such as steel and non-ferrous alloys now compete with non-metallic materials, notably polymers, as well as with each other. Hence, advanced alloy-design concepts are being exploited in microalloyed steels, inclusion-engineered steels, aluminum-lithium alloys, and spinodally-hardened copper alloys to meet ever increasing property requirements. Equally significant is the extensive development of "engineered materials" which are a synthesis of metallic and non-metallic components, produced by novel processes to achieve properties superior to those of the traditional alloys. Examples are rapidly-solidified materials, surface-engineered alloys, composite materials, and advanced structural ceramics.

MICROALLOYED STEELS

In the continued development of microalloyed steels, the quench-deformation dilatometer is used to simulate thermomechanical processing and to determine the transformation kinetics. Fundamental data on the effects of microalloying elements and thermomechanical treatment have been obtained by this means to model the behaviour of microalloy steels in commercial processes. The work emphasizes plate-steel chemistries, specifically steels microalloyed with Nb, Nb+V, Nb+Cr-Mo or -W, and Ti+V, as well as ultra-low carbon bainitic steels. Dilatometer simulations generally produce microstuctures comparable to those found in laboratory-rolled plate. Notably, on-line accelerated cooling treatments for plate were developed from dilatometer results, and considerable progress was made in understanding how to control the distribution of boron during plate rolling. The strength and fracture toughness of microalloyed plate steels was correlated with their microstructures, and specific microstructural sources of brittleness and reduced ductility were identified. Fracture maps are being constructed which depict the critical stress or strain for fracture as a function of microstructure and test temperature.

INCLUSION ENGINEERED STEELS

Techniques are being developed for characterizing inclusion distributions by automatic image analysis because it is important to determine the type, size and distribution of the various inclusions which occur in steels produced by modern steelmaking processes. Procedures have been developed for characterizing particle-spacing distributions and for classifying inclusions based on their chemistry. Research on "inclusion-engineered" steels has focused on the control of inclusions in medium-carbon steels to improve machinability. The effects of inclusions and other second-phase particles on chip formation and tool wear have been determined as a function of cutting speed. In a related project, a thermodynamic data-base was developed to support the treatment of steel with calcium in the ladle to produce specific inclusion phases. An international symposium was organized on "Effects and Control of Inclusions and Residuals in Steel".

OTHER STEELS

In collaboration with a steel company and a spring manufacturer, experimental steels for automotive coil springs were prepared and evaluated. Tensile tests and microstructural studies showed that increased yield strength and satisfactory hardening can be achieved by high silicon content and/or microalloying. In collaboration with the National Research Council,the effect of rail-steel microstructure on simulated rail-head wear was investigated. The results were used to design accelerated cooling treatments to produce head-hardened rail with an optimum microstructure. Service failures of tank cars, wheels and rails were investigated for the Canadian Transport Commission, and recommendations were made for improved materials specifications.

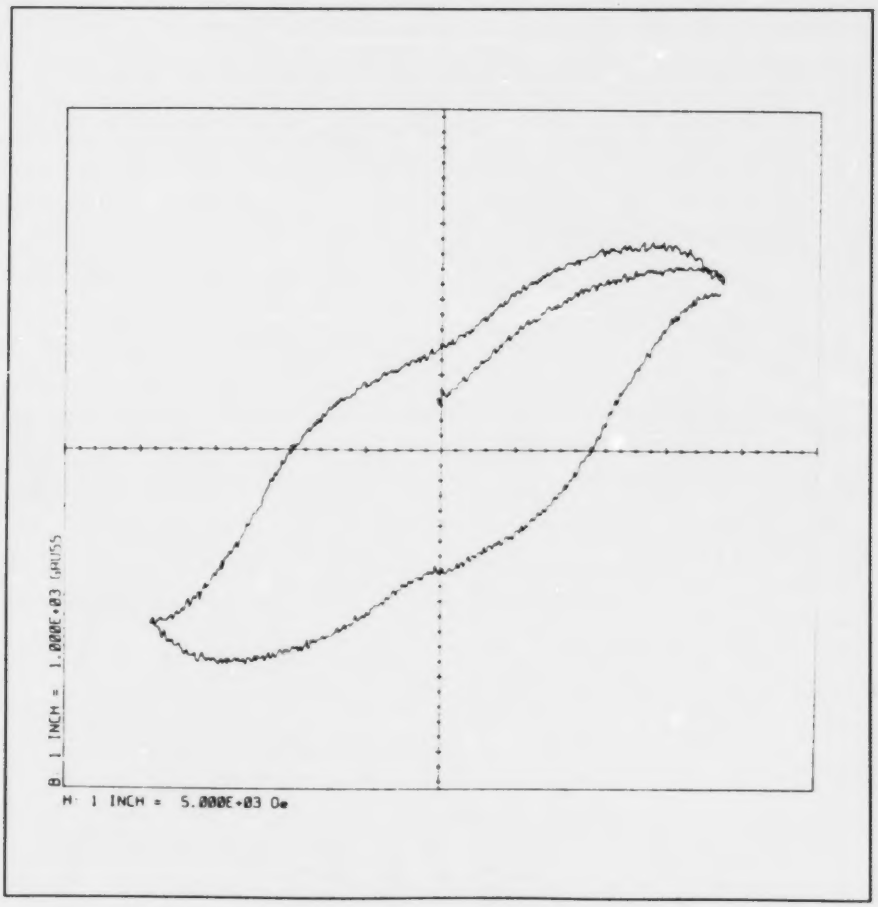
NON-FERROUS ALLOYS

Work continues on the quantitative microanalysis of light elements at high spatial resolution by electron energy loss spectroscopy. In collaboration with scientists in Canada, the U.S. and U.K., calibration factors for quantitative EELS analysis were determined for a large number of elements. Procedures have also been established for preparing thin sections of metals, ceramics and composites by diamond knife ultramicrotomy. These techniques were used to characterize the distribution of lithium in experimental and commercial Al-Li alloys , and to determine concentrations of impurity elements in ceramic materials.An extensive study is being carried out on the strength, fracture toughness and fatigue/corrosion fatigue resistance of Mn-Ni-Al bronze propeller alloys.The effects of alloy composition and processing variables are

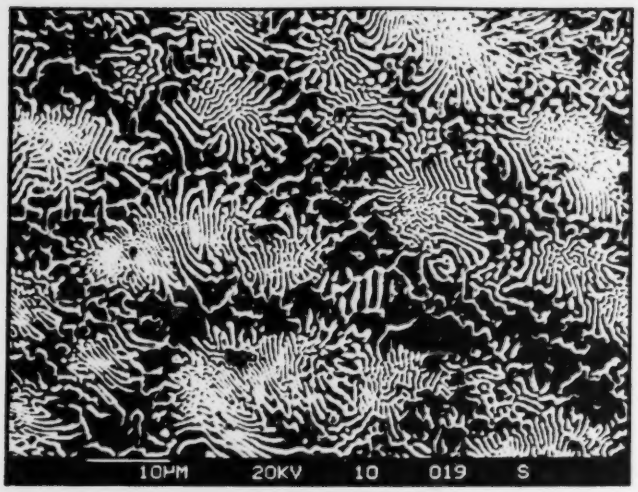
being investigated particularly on the toughness of the alloys. In slowly cooled (heavy section) sand castings, a striking reduction of toughness occurs. The changes in microstructure responsible for the embrittlement have been identified and a remedial heat treatment developed which doubles the impact toughness of commercial propeller castings without sacrifice in strength.

RAPIDLY SOLIDIFIED MATERIALS

Melt spun iron-neodymium-boron alloys have exceptionally high magnetic field strengths and are candidate materials for compact permanent magnets, suitable for space vehicles, robots and small engines. Melt-spun flakes of Fe-Nd-B alloys have been prepared and their magnetic properties characterized with a newly-commissioned hysteresigraph. Permanent magnet materials are being fabricated by consolidating melt-spun flakes as well as by dispersing the flakes in polymer-matrix composites.The production of amorphous coatings of stainless steel has been achieved by co-sputtering 304 SS with ~ 10 a/o Zr at high metal gas temperatures. A model has been proposed which

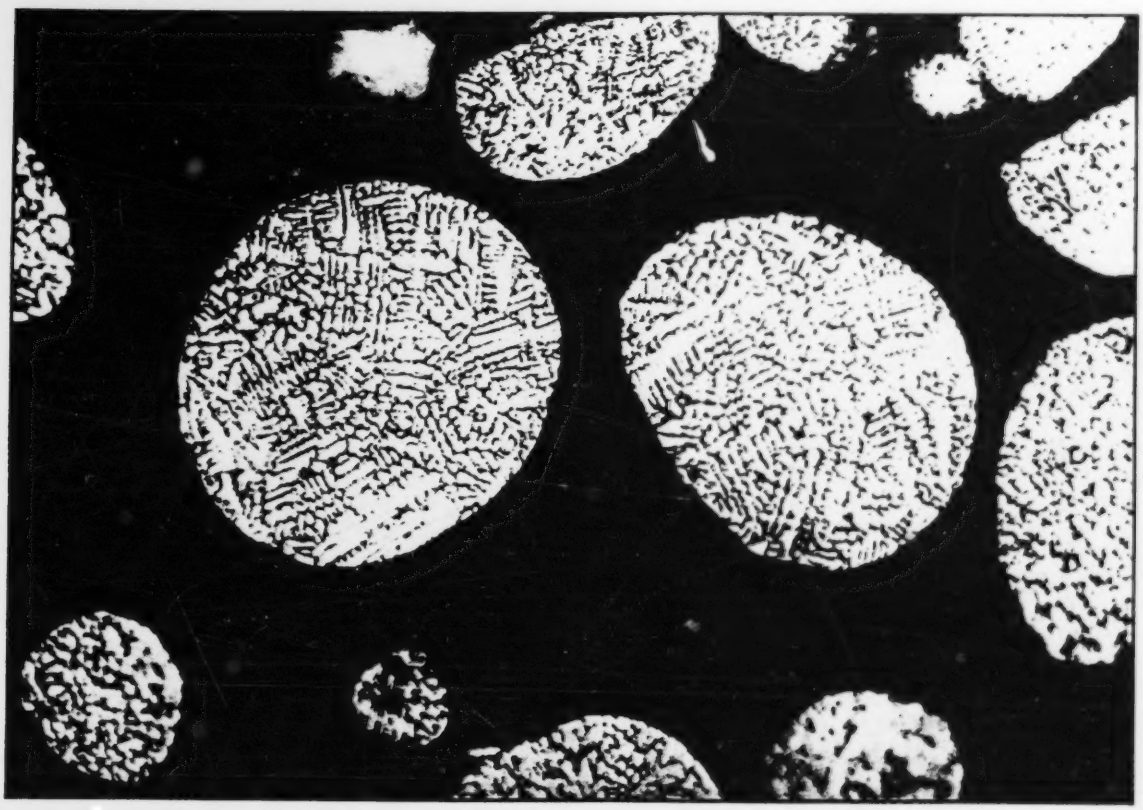


Magnetic hysteresis curve for rapidly solidified Fe-Nd-B demonstrated a magnetic strength of 5 milion gauss-oersteds.



Eutectic structure of Fe_3Zr and delta ferrite in arc melted Grade 304 stainless steel containing 12 wt % Zr.

explains the stabilization of defect structures in rapidly-quenched alloys by impurity atoms on the basis of their volume misfit. It is anticipated that such amorphous coatings will exhibit exceptional corrosion resistance.In collaboration with Waterloo University, the production and properties of composites reinforced with metallic glass ribbons are being investigated. To date Fe40Ni40B20-polypropylene composites made by hot compaction and Ni75Al23B1Zr1-aluminum composites made by casting have been evaluated.In collaboration with National Defence (DREA), studies on melt-spun Fe-Al bronzes are underway. The enhanced solid solubility of iron in these alloys and their superior corrosion



Rapidly solidified Cu - 6 wt % Al - 3 wt % Fe powder, using He by Ontario Research Foundation (x 500)

resistance compared with conventionally-processed material has been demonstrated. Rapidly-solidified powders of these alloys prepared by gas atomization have been obtained, and techniques are being developed to consolidate the powder by extrusion. In a related project, high energy rate compaction is being investigated as a means of consolidating rapidly solidified materials; fundamental studies on iron powders have yielded well-bonded, high-density compacts. In other work on rapid solidification, the direct casting of Cu-Ni-Sn strip is being investigated (in collaboration with Noranda and the National Research Council (IMRI)). It has been shown that rapid solidification eliminates macrosegregation, and significantly reduces microsegregation in these alloys.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Metallurgy Section are underlined)

Collins, L.E., Knight, R.F., Ruddle, G.E., and Boyd, J.D.
"Laboratory development of accelerated cooling of microalloyed plate steels"; Accelerated Cooling of Steel; Ed. P.D. Southwick; Pittsburgh, PA; Aug. 1985; TMS-AIME; 261; 1986.

Couture, A., and Sahoo, M.
"Microstructure and mechanical properties of heat treated concast Mn-Ni-Al Bronzes";Transactions of American Foundrymen's Society; 94; 671; 1986.

Fegredo, D.M., Kalousek, J., Shehata, M.T., and Palmer, A.
"The effect of sulphide and oxide inclusions on the wear rates of standard and alloy rail steels"; Third International Heavy Haul Railway Conference; Vancouver, B.C; Oct 1986; Int. Heavy Haul Assn.; Paper IB-14; 1986.

Gilmour, J.B., Lui, A.W., Briggs, D.C., Knight, R.F. and Hindam, H.
"The Canadian atmospheric fluidized bed combustion materials program: Part I - Performance of alloys after 10 000 h exposure; Corrosion 87; San Francisco , CA; March 1987; NACE;15-1; 1987.

Laufer, E.E., Fegredo, D.M., and Kalousek, J.
"The effect of microstructure on wear in standard and head-hardened rails in heavy haul service"; Third International Heavy Haul Railway Conference; Vancouver, B.C; Oct 1986; Int. Heavy Haul Assn.; Paper I-16; 1986.

Sahoo, M., and Couture, A.
"A review of CANMET work on high-strength copper-base casting alloys for ships and systems"; Beijing International Foundry Conference; Beijing, China; Oct., 1986; Foundry Institute of the Chinese Mechanical Engineering Society; 1289; 1986.

Shehata, M.T., Chandel, R.S., Braid, J.E.M., and McGrath, J.T.
"Characterization of non metallic inclusions in weld metals"; Microstructural Science 14; 65;.1986.

Shehata, M.T., and Boyd, J.D.
"Assessment of non metallic inclusions in steels by automatic image analysis"; Effects and Control of Inclusions and Residuals in Steels; Toronto, Ontario; Aug. 1986; CIM-METSOC; III:19; 1986.

AVAILABLE PMRL REPORTS

PMRL 85-39 (TR)	Laboratory simulation of flash-butt welding of rail (Interim report) D.M. Fegredo, L.E. Collins and J.T. Bowke
PMRL 86-39 (TR)	EMR/NSPC. AFBC materials program. Evaluation of the probe removed at the end of run 9. J.B. Gilmour, A. Lui, D. Briggs and R.F. Knight
PMRL 86-64F (INT)	Program COD. M. Collette
PMRL 86-85 (INT)	Recommendations for the development of PMRL capabilities for the production of rapidly solidified alloys in bulk forms. L.E. Collins
PMRL 86-89 (a) (INT)	Full day rail meeting at NRC's Western lab, Vancouver, B.C. October 13/86 D.M. Fegredo
PMRL 86-89 (b) (INT)	3rd Int'l heavy haul conf. report Oct. 14-17, 1986. D.M. Fegredo

Pouring rates for copper-base alloys. J.O. Edwards and M. Sahoo	**PMRL 86-3(OP-J)**
A review of CANMET's work on high-strength copper-base casting alloys for shipboard systems. M. Sahoo and A. Couture	**PMRL 86-18(OP-J)**
The effect of sulphide and oxide inclusions on the wear rates of standard and alloy rail steels D.M. Fegredo, J. Kalousek, M. Shehata and A. Palmer	**PMRL 86-23(OP-J)**
Effects of heat treatment and manganese content on the properties of continuously cast Mn-Ni-Al bronzes. A. Couture and M. Sahoo	**PMRL 86-37 (OP-J)**
Rapidly solidified metals. L.E. Collins and Z.S. Wronski	**PMRL 86-54 (OP-J)**
Assessment of non-metallic inclusions in steels by automatic image analysis. M. Shehata and J.D. Boyd	**PMRL 86-55 (OP-J)**
Selected results after 5000 h exposure in the Canadian AFBC materials program. J.B. Gilmour, H. Hindam, A.W. Lui, D.C. Briggs and R.F. Knight	**PMRL 85-56 (OP-J)**

Fourteen Cost Recovery Reports were completed by the Metallurgy Section in FY 86/87.

PRESENTATIONS

(Presenting authors from the Metallurgy Section underlined)

Boyd, J.D.
"New steels for oil country tubulars"; Calgary Chap.of ASM; Calgary, Alta.; May 1986

Boyd, J.D.
"New steels for oil country tubulars"; N. Ontario Chap.of ASM; Sault Ste. Marie, Ont.; Sept. 1986.

Boyd, J.D.
"Microstructural effects on fracture in a Ti-V plate steel"; NRC-IMRI; Boucherville, Quebec; Jan. 1987.

Collins, L.E., McDougall, J.M., and Boyd, J.D.
"The Effects of Cr, Mo and W on the transformation behavior of a Nb-microalloyed steel"; TMS Annual Meeting; Denver, CO; Feb. 1987.

PRESENTATIONS (CONTINUED)

Collins, L.E.
"Update on Canadian activities in rapid solidification technology"; Seminar on Rapid Solidification Technology; Winnipeg, Man.; Apr.1986.

Collins, L.E. and Wronski, Z.S.
"Rapidly quenched metals"; New Metallic Materials and New Fabrication Processes; Montreal, Quebec; July 1986.

Collins, L.E. and Mitrovic-Scepanovic, V.
"Microstructures and properties of rapidly solidified Fe-Al bronzes"; 25th CIM Conference of Metallurgists; Toronto, Ont.; Aug. 1986.

Collins, L.E. and Mitrovic-Scepanovic, V.,
"The development of improved Fe-Al bronzes by rapid solidification; 116th TMS Annual Meeting; Denver, CO; Feb.1987.

Couture, A., and Sahoo, M.
"Microstructures and mechanical properties of heat-treated concast Mn-Ni-Al Bronzes"; 90th AFS Casting Congress; Minneapolis, Min; May 1986.

Fegredo, D.M., Kalousek, J., Shehata, M.T., and Palmer, A.
"The effect of sulphide and oxide inclusions on the wear rates of standard and alloy rail steels; Third International Heavy Haul Railway Conference; Vancouver, B.C.; Oct.1986.

Fegredo, D.M., and Kalousek, J.
"The effect of mixed microstructures on wear"; Second International Symposium on Contact Mechanics and Wear of Rail/Wheel Systems; Rhode Island University, Kingston, R.I.; July 1986.

Himbeault, D., Varin, R.A., Piekarski, K., and Wronski, Z.S.
"A study of interfacial reactions during the deformation of an aluminum matrix composite"; Canadian Metal Physics Conference; Kingston, Ont.; June 1986.

Malis, T., Rajan, K., Weatherly, G.C., and Titchmarsh, J.M.
"EELS quantification and its range of validity; NRC Workshop on Intermediate Voltage Microscopy; NRC, Ottawa, Ont.; June.1986.

Malis, T.
"New developments in EELS ; Microscopy Society of Canada Annual Meeting; McMaster Univ. Hamilton, Ont.; June.1986

Malis, T.
"An experimentalist approach to EELS quantification"; 11th Int. Conf. on X-ray Optics and Microanalysis ; London, Ont.; Aug.1986

PRESENTATIONS (CONTINUED)

Malis, T., Vogan, B., and Boyd, J.D.
"Characterization of an unusual transformation product in a microalloyed steel (poster presentation); Metal Physics Conference; RMC, Kingston, Ont.; June.1986.

Gilmour, J.B., Lui, A., Knight, R.F., and Hindam, H.
"Corrosion in an atmospheric fluidized bed combustor"; Canadian Eastern Region NACE Conf.; Halifax, NS; Nov. 1986.

Gilmour, J.B., Lui, A., Knight, R.F., and Hindam, H.
"Corrosion in an atmospheric fluidized bed combustor"; Canadian Eastern Region NACE Conf.; Halifax, NS; Nov. 1986.

Ozsoy, I.C., Ruddle, G.E., Dogan, B. and Crawley, A.F.
"Optimization modelling of hot-rolling practices applied to Ti-V microalloyed steel"; Symposium on Computer Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa, Ont.; May 1986.

Parsons, D.E., Fegredo, D.M., Sastri, V.S.
"Hydrogen degassing to safe levels in alloy and standard C-Mn steels by controlled cooling; (Poster Presentation) 36th Canadian Metal Physics Conference; Kingston, Ont.; June 1986.

Parsons, D.E., Fegredo, D.M., and Sastri, V.S. (Poster Sesson presented by J.D. Boyd)
"Hydrogen degassing to safe levels in alloy and standard C-Mn Rail steels by controlled cooling"; 25th Annual Conference of Metallurgists; Toronto, Ont.; August 1986.

Shehata, M.T., and Boyd, J.D.
"Assessment of non-metallic inclusions in steels by image analysis"; CIM Conference of Metallurgists; Toronto, Aug. 1986.

Shehata, M.T.
"Image analysis in microstructural characterization of steels"; Seminar Dept . of Metallurgy, Cairo University; Cairo, Egypt; Jan. 1987.

Tandon, K.N., and Collins, L.E.
"Corrosion-fatigue behaviour of metallic glasses"; 25th CIM Conference of Metallurgists; Toronto, Ont.; Aug. 1986.

Wronski, Z.S.
"Rapidly Solidified iron-Boron alloys for electromagnetic and electronic applications"; Conf. of Metallurgists; Toronto, Ont.; August 1986.

Wronski, Z.S.
"Amorphous steels and Fe-Zr alloys"; TMS Fall Meeting; Orlando, Fl.; October 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J.D. Boyd	McMaster University	Metallurgical aspects of machinability in medium carbon steels.
J.D. Boyd	Ecole Polytechnique	"Fracture toughness and corrosion fatigue of bronze propeller alloys.
J.D. Boyd	Queen's University	A study of the dissolution of elements in liquid aluminum.
L. E. Collins	Dr. Krishnadev Laval University	Ultra to low carbon boron HSLA steels: Influence of alloying and processing on the transformation kinetics and mechanical properties
L.E. Collins	Ontario Research Foundation	Atomization of rapidly solidified Fe-Al bronze powders
L.E. Collins	Limpact Industries Ltd.	High energy rate compaction of rapidly solidified powders
L.E. Collins	Manitoba Research Council	An investigation of the corrosion fatigue behaviour of magnetic metallic glasses.
L.E. Collins	Noranda	Rapidly solidified high performance copper alloys for electronic connectors.

SA/LO	Performer	Project
L.E. Collins	Dr. C. Roy University of Sherbrooke	Relation entre l''état amorphe d'alliages industriels et l'amélioration de leurs propriétés mécaniques
D.M. Fegredo	Dr. E.E. Laufer, Technichal University of Nova Scotia	Transmission electron microscope study of wear in a disk of standard (C-Mn) rail composition in the laboratory.
T. Malis	Prof. J.D. Embury	Control of recrystallization in Al alloys.
Z.S. Wronski	International Sigma Security Inc. and Prof. Strom-Olsen, McGill University.	Tag development

COMPLETED RESEARCH CONTRACT REPORTS

Compacting characteristics of rapidly solidified particulates.
Performer: Sherritt Research Centre, Sherritt Gordon Mines Ltd.
Scientific Authority L.E. Collins

An investigation of the corrosion fatigue behaviour of magnetic metallic glasses
Performer: Manitoba Research Council.
Scientific Authority L.E. Collins

High energy rate compaction of rapidly solidified metal powders.
Performer: Limpact industries Ltd.
Scientific Authority L.E. Collins

The development of rapidly solidified stainless steel alloys for powder metallurgy applications
Performer Sinteris Canada Ltd.
Scientific Authority L.E. Collins

METALS PROCESSING LABORATORY

MANAGER **R. THOMSON** **995-9541**

*	FOUNDRY SECTION	5-1
*	METAL FORMING SECTION	6-1
*	NONDESTRUCTIVE TESTING SECTION	7-1
*	WELDING SECTION	8-1

Foundry Section

Section Head	R.K. Buhr	992-5095
Deputy Section Head	R.D. Warda	992-0949

FOUNDRY SECTION

LOW PRESSURE DISPOSABLE MOULD CASTING.

The development of this technique for the production of aluminum castings is nearing completion, and the process has been demonstrated to several industrial clients, including Ford and General Motors. Work has also progressed in the production of castings in higher melting point alloys (copper-base and cast irons) using the modified ladle technique. These have proven to be successful, and the information was presented at a seminar on evaporative foam casting in November, 1986.

This work has led to a further development which is applicable not only to the evaporative foam casting process, but also to green and no-bake sand moulds as well. It is a bottom pouring technique which lends itself to an economical automatic pouring method which has potential for use even in smaller low production shops. A patent search is currently underway on this technique and work on the modified ladle technique has been suspended in favour of this new process.

GRAVITY PERMANENT MOULD CASTING

The work on Inmold ductile iron is now complete. Dross in the castings remained a severe problem, despite the use of various types of ceramic filters. Equipment was constructed in which the magnesium treatment was conducted in a box mounted above the permanent mould. The box incorporated both the reaction chamber, and a holding chamber to allow time for dross to float out of the metal. With this arrangement castings lower in dross were produced, but more chill was present than in castings where the reaction chamber was in the mould itself.

Three aluminum alloys, namely pure aluminum, A1-7% Si, and "A390" alloy (17% Si) have been tested as candidate materials for water-cooled moulds to be used in casting the higher melting point metals. Cast iron or steel were poured in moulds of simple shape. The A390 alloy mould was not successful, showing burn-in after less than 50 castings had been poured. The pure aluminum and A1-7% Si alloy both gave over 50 castings with no significantdegradation in the mould surface itself. Both, however, showed some

attack on the mould parting surfaces adjacent to the casting where metal flash was present. A more complex mould, which incorporates ejector pins, has been made to produce small wheel-shaped castings. Early tests have shown problems with ejection, and cracks in the castings due to reduce mould restraint. A redesign is underway to reduce mould restrained stresses and to facilitate ejection.

The computer model for solidification of metals in permanent moulds, written under contract, is nearing completion. The role of convection is more important in permanent moulds than in sand moulds, and latterly the main effort has been directed toward a treatment of convective phenomena within the mould cavity. Rigorous treatment of convective flows, are however, complex, and it remains to be seen if a "user-friendly" version of the program incorporating this feature can be written.

CANMETCOAT Digger Teeth

A commercial foundry has poured a series of CANMETCOAT digger tooth castings for testing at Syncrude. Initial results are encouraging, and renewed interest in the process has ensued as a result.

A contract has been awarded to model penetration of the poured metal into the layer of abrasion-resistant powder material positioned on the mould cavity surface of a CANMETCOAT casting. It is hoped that the model will lead to a better understanding of the penetration process, which in turn may lead to better control of the variables that determine the maximum thickness of coating that can be applied.

Electroslag Casting

Nickel-aluminides possess excellent high temperature properties and, as such, are of considerable interest. However, these alloys are difficult to hot or cold work, and this has severely limited their commercial utilization. Part of the problem lies in a coarse grain size in the as-cast condition, and the U.S. Department of Energy, through their Oakridge Laboratories, have been investigating the problem.

CANMET has one of the few experimental electroslag casting facilities in North America, and so were asked by Oakridge to undertake the production of nickel-aluminide electroslag cast billets, to determine whether this technique would result in improved cold working characteristics.

Several billets have been made, and some modifications to the composition have also been investigated, making the alloy less expensive. They have all

proved beneficial, and over 50% cold working has been achieved, an unheard of figure. In addition, a novel technique is being investigated which results is fine grain sizes being achieved in the electroslag casting. This aspect is also being investigated further to determine if the technique is applicable to other alloys.

The electroslag casting facility is also being used for the production of ultra-low sulphur melting stock for the production of controlled cleanliness steels in the vacuum induction furnaces. The process permits sulphur contents of 0.001% to be achieved.

ZINC-ALUMINUM ALLOYS

The work on this project is almost completed. The past year has been involved with establishing the corrosion characteristics of the alloys modified with strontium, sodium or calcium. This work was performed by Cominco in their steam cabinet and showed strontium-modification to have been successful in that the corrosion properties had not deteriorated. This was not the case with the sodium modification. The calcium-modified tests are being repeated because of the presence of an unknown impurity in the alloy.

The suggestion by Queen's University to use rare earths was shown to require up to 0.40% total of La, Ce, Pr and Nd to be as effective as a 0.04% Sr addition.

BRONZE ICE-BREAKER PROPELLER ALLOYS

Following the successful development of an industrially practicable remedial heat treatment to improve the impact toughness of the existing Mn-Ni-Al bronze propeller alloys containing about 14% Mn, work is in progress to redefine the composition ranges, especially those of aluminum and manganese, of these bronzes so that high impact toughness can be obtained even in the as-cast condition of the large propellers. These propellers need not be heat treated to produce further improvements in their impact toughness.

A comprehensive study is being carried out on the fracture toughness of Mn-Ni-A1 propeller bronzes with manganese contents ranging between 8 and 14% and on the influence of different heat treatments on their fracture toughness. A detailed combined fractographic-metallographic study is also being carried out to evaluate the relationship between the microstructure and the fracture toughness under a contract with Ecole Polytechnique in Montreal. Preliminary result show that the JIc and JId fracture toughness values of these alloys decreases as the manganese content increases.

AUSTEMPERED DUCTILE IRON (ADI)

Austempering ductile iron results in a significant increase in the tensile and yield strengths of the alloy with little loss in elongation. As a result it is receiving considerable attention as a potential replacement for steel parts. Modifications to the austempering treatment can also result in significant increases in wear resistance.

One of the problems with this treatment is the adverse effect certain elements have on the heat treatment response; manganese will segregate to cell boundaries and transform to martensite during the austempering treatment embrittling the material. Other alloys, such as molybdenum also segregate, but with less disastrous effects. As most of the elements which apparently cause problems are carbide stabilizers, and because of the increasing problem of residuals in raw materials and scrap used in the production of ductile iron, a project has been undertaken at CANMET to systematically investigate the effects of certain residual elements on the heat treatment response and mechanical properties of ADI. The elements selected are Cr, V, Ti and Sb, and the effects will be determined in both 1 and 3 inch sections. The work on the 1 inch sections should be completed in the next fiscal year.

FOUNDRY WORKSHOPS

Regional workshops were held in Vancouver, Edmonton, Winnipeg and St. Hyacinthe during the past fiscal year. The topic of the workshops was "Gating and Risering of Castings" and they were performed with the cooperation of the American Foundrymens Society in these areas who paid for all the travelling and living expenses of those presenting the workshops. Participation was very good with a total enrollment for the four workshops of about 70 people who represented a good cross-section of the industry. These workshops were well received and there have been numerous requests to continue them in the future. As a result, a further series of regional workshops is planned for the next fiscal year on electric furnace melting practice and cost control.

DISPERSION-HARDENED METAL CASTINGS

The majority of dispersion-hardened metallic parts are formed by powder metallurgical techniques. It was thought desirable to employ this technique directly as a casting process. To achieve this would mean the dispersoid and the matrix must be mutually insoluble and they should be of similar density. These criteria limit the choice of materials severely. Copper and molybdenum carbide do fulfil the above restrictions and efforts have been directed towards

producing cast parts in this system. Because it is extremely difficult to introduce finely divided particles into liquid metal, it was decided to prepare a "master composition" by mixing powders of copper, molybdenum and molybdenum carbide and fusing them into a solid, which could then be remelted and diluted appropriately to the desired composition as in other foundry operations.

This has been done but the resulting mass showed areas of distinct segregation, some having a good dispersion of the MoC_2 in the copper matrix, and others containing little or no MoC_2. The attached macrophotograph illustrates this pattern. Work is continuing in this area to overcome this problem.

ULTRA CLEAN STEELS

The 225 kg vacuum induction furnace is now in regular use to produce steel ingots of controlled composition and with restricted quantities of non-metallic inclusions, for use in research both at PMRL and by other organizations. Nitrogen contents as low as 15 ppm and sulphur contents of 20 ppm are reached through selection of raw materials and use of appropriate precautions during melting.

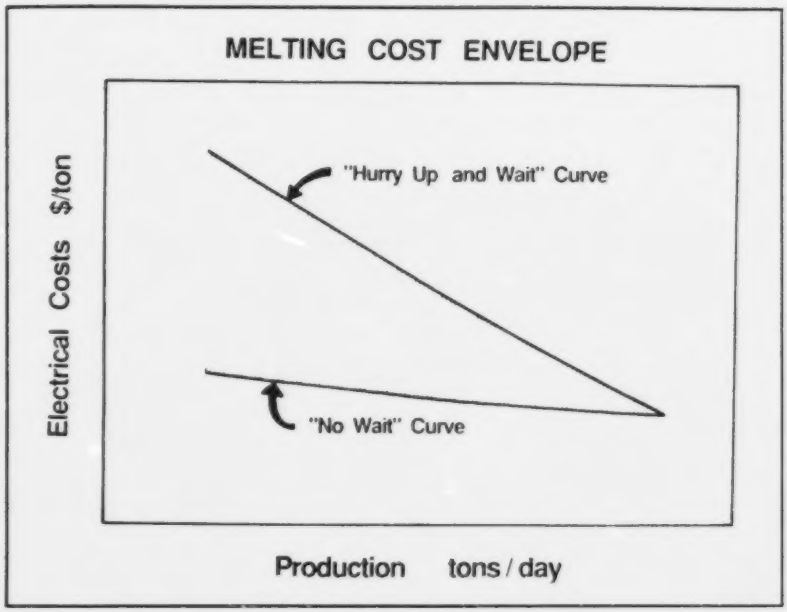
Oxygen contents of about 35 ppm can be obtained in the vacuum-melted steel but levels below 20 ppm are needed. It is hoped that the use of different furnace linings will eliminate the suspected side reactions that introduce oxides into the steel.

The powder injection equipment is being used experimentally and sulphur has been removed from air melts to levels as low as 7 ppm, although there was an unwanted gain in the silicon content. Other reagents are being tested to avoid this disadvantage.

ELECTRIC FURNACE COST ANALYSIS

Detailed and comprehensive analyses were performed at six Ontario foundries to determine the cost of melting cast iron in mains-frequency induction furnaces. Standard unit costs were used to calculate the total metal cost at the spout. These costs ranged from $214 to $270 per ton for five coreless furnaces. The cost for a vertical channel furnace was $239 per ton. A spreadsheet model, based on furnace cycle energy balances, was used to analyze the electrical costs for actual and hypothetical melting campaigns. The actual foundry melting costs lay on a curve defining the maximum electrical cost. This curve, called the "hurry up and wait" curve, and a minimum cost, "no wait", curve

The "Hurry up and Wait" curve and the minimum cost "No Wait" curve generated by a spreadsheet model to produce an envelope of practicable operation for furnace systems



were generated by the model to produce an envelope of practicable operation for each furnace system, as shown below. The model was also used to identify variables which controlled both the movement of the melting cost within the envelope and the location of the envelope itself. Application of these concepts to actual operations identified significant savings which could be obtained by changing operating practices. For example, savings of $2 to $8/ton in electrical costs could be achieved if the applied power and unnecessary delays were minimized at constant production. A further savings of up to $25/ton could be realized if production could be increased to the maximum permitted within the envelope. Where practicable, movement of the operating envelope could result in a significant additional saving. Analyses of furnace and plant demand patterns indicated that demand control and management could save up to $7000/month at certain foundries.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Foundry Section are underlined)

Ayik, O., Ghoresky, M., Sahoo, M. and Smith, R.W. "Solidification and foundry studies of Zn/Al alloys"; Journal of Crystal Growth; 79; 594; 1986.

Buhr R.K.
"Technology transfer using a mobile foundry laboratory"; Beijing International Foundry Conference; Beijing, China; Oct., 1986; Foundry Institute of the Chinese Mechanical Engineering Society; 1344; 1986.

Couture, A., and Sahoo, M.
"Microstructure and mechanical properties of heat treated concast Mn-Ni-Al bronzes"; Transactions of the American Foundrymen's Society; 94; 671; 1986.

Sahoo, M.
"Mechanical properties characterization of slow-cooled aluminum bronzes"; Transactions of the American Foundrymen's Society; 94; 97; 1986.

Sahoo, M., Whiting, L.V., Chartrand, V. and Weatherall, G.
"Effect of Strontium on the structure and mechanical properties of zinc-aluminum foundry alloys";Transactions of the American Foundrymen's Society; 94; 225 1986.

Sahoo, M., and Couture, A.
"A review of CANMET work on high-strength copper-base casting alloys for ships and systems"; Beijing International Foundry Conference; Beijing, China; Oct., 1986; Foundry Institute of the Chinese Mechanical Engineering Society; 1289; 1986.

Szabó E.I., Gauthier, R., and Kular, A.C.
"Two novel cold set foundry binder systems"; American Foundrymen's Society; Minneapolis, MN; May 12-15; AFS; 433; 1986.

AVAILABLE PMRL REPORTS

Conversion of Jarrell Ash data files to files for the Queen's University statistical process control program. L.V. Whiting	**MRP/PMRL 84-45 (INT)**
Evaluation of seven additional sand samples for foundry use: Canadian silica study (Quebec). E.I. Szabo and A.C. Kular	**MRP/PMRL 85-54 (INT)**
Two novel cold-set foundry binder systems.E.I. Szabo, R. Gauthier and A.C. Kular	**PMRL 85-63 (INT)**
Notes on programs to compute charges and late alloy additions for PMRL steel melts. A.R. Palmer	**PMRL 86-42 (INT)**

PMRL 86-44 (INT)	Nitrogen in air-induction melts of steel made at PMRL. A.R. Palmer
PMRL 86-27 (TR)	Analysis of high chromium and Ni-Hard abrasion resistance cast irons in the Mobile Foundry Laboratory. L.V. Whiting
PMRL 86-28 (TR)	Analysis of Fe-Cr and Fe-Cr Ni stainless steels in the Mobile Foundry Laboratory. L.V. Whiting
PMRL 86-41 (TR)	Calculation of AFS grain fineness and screen distribution of sands for the Apple II micro-computer. L.V. Whiting and R. Matte
PMRL 86-6 (OP-J)	Two novel cold-set foundry binder systems. E.I. Szabo, R. Gauthier and A. Kular
PMRL 86-9 (OP-J)	Technology transfer using a mobile foundry laboratory. R.K. Buhr
PMRL 86-23 (OP-J)	The effect of sulphide and oxide inclusions on the wear rates of standard and alloy rail steels. D.M. Fegredo, J. Kalousek, M. Shehata and A. Palmer
PMRL 86-61 (OP-J)	New developments in the foundry industry. K.G. Davis
	One cost recovery report and numerous Mobile Foundry Laboratory Reports were completed in FY 86/87

PRESENTATIONS

(Presenting authors from the Foundry Section underlined)

Abdullah, Z., Salcudean, M., and Davis, K.G.
"Modeling the solidification of cast iron in permanent moulds"; Computer Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa, Ont.; May 198

Buhr, R.K.
"Technology transfer using a mobile foundry laboratory"; Beijing International Foundry Conference; Beijing, China; Oct. 1986.

Buhr, R.K., Davis, K.G. and Magny, J.G.
"Workshops on gating and rising"; Vancouver, B.C., Nov. 1986; Edmonton, Alberta, Dec. 1986; Winnipeg, Man., Dec. 1986.

Buhr, R.K.
"Sand control in Canadian foundries"; Soundness and Quality in Cast Metals II; Kingston, Ont.; Sept. 1986.

Couture, A., and Sahoo, M.
"Microstructure and mechanical properties of heat treated concast Mn-Ni-Al bronzes"; 90th AFS Casting Congress; Minneapolis, Min.; May 1986.

Davis, K.G.
"Foundry aids-an overview"; Soundess and Quality in Cast Metal II; Kingston, Ont.; Sept. 1986.

Davis, K.G.
"New developments in the foundry industry"; Cour et conference sur les nouveaux procedes de fabrication; IGM/IMRI Boucherville, Quebec; July 1986.

Davis, K.G., Ding Hui, Magny, J.G., Brown, D.A.
"Inmold production of ductile iron in permanent moulds"; Advanced Casting Technology -International Conference and Exposition; Kalamazoo, MI; Nov.1986.

Davis, K.G.
"Pièces coulées en moules permanents pour des alliages à haut point de fusion"; American Foundrymen's Society; Montreal, Quebec; Feb.1987.

Davis, K.G.
"Workshops on gating and risering"; Vancouver, Edmonton, Winnipeg, Nov. 1986, St. Hyacinthe, Mar. 1987.

Jincheng, Xu, Palmer, A.R.
"Studies on alumina inclusions in liquid steel and ingots"; Beijing International Foundry Conference; Beijing, P.R. of China; Oct. 1986.

Sahoo, M.
"Mechanical properties characterization of slow-cooled aluminum bronzes"; 90th AFS Casting Congress; Minneapolis, Min.; May 1986.

Sahoo, M., Whiting, L.V., Chartrand, V., and Weatherall, G.
"Effect of stontium on the structure and mechanical properties of zinc-aluminum foundry alloys"; 90th AFS Casting Congress; Minneapolis, Min.; May 1986.

Sahoo, M.
"Non-ferrous foundry developments - copper base alloys"; Soundness and Quality in Cast Metals-II; Kingston, Ont.; September 1986.

Sahoo, M., and Couture, A.(Presented by R.K.Buhr)
"A review of CANMET work on high strength copper base alloys for shipboard systems"; Beijing International Foundry Conference; Beijing, China; Oct.1986.

Warda, R.D.
"Evaluation of Canadian foundries by the MFL"; Northwest Regional Conference of the AFS.

Warda, R.D.
"Reduction of electric furnace melting costs"; Eastern Canada Chapter of the AFS,.May 1986.

Warda, R.D.
"Sensors and controls in foundries"; Soundess and Quality in Cast Metal II; Kingston, Ont.; Sept. 1986.

Whiting, L.V.
"Cupola and Induction Furnace Melting Costs"; Soundess and Quality in Cast Metal II; Kingston, Ont.; Sept. 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
R.K. Buhr	Kanata Consulting Group	An evalation of the visits of the Mobile Foundry Laboratory by O.R.F. and CRIQ.
K.G. Davis	Univ. of Ottawa	Mathematical modelling of temperature fields and thermal stresses in permanent moulds.

SA/LO	Performer	Project
K.G. Davis	Falconbridge	Influence of casting variables on the structure and properties of cast heat-resistant alloys.
K.G. Davis	Arctec	Modelling of molten metal penetration into a particulate
K.G. Davis	McGill University	Applications of strontium in the foundry industry.
A.R. Palmer	Prof R.I.L. Guthrie, McGill University, Montreal.	Instrumention for on-line liquid metal quality control in iron & steel making
A.R. Palmer	Prof. G.A. Irons McMastor University, Hamilton.	Optimization of injection technology for high-quality steel - Phase II: Calcium treatment of steel.
M. Sahoo	Dr. R.W. Smith, Dept. of Met. Eng., Queen's University, Kingston, Ontario.	The design and production of high quality nonferrous castings.

COMPLETED CONTRACT RESEARCH REPORTS

An Evaluation of the Mobile Foundry Laboratory by its Clients.
Performer: Kanata Consulting Group
Scientific Authority R.K. Buhr

Metal Forming Section

Section Head A.F. Crawley*

*(On Secondment to the Research Program Office)

A/Section Head G.E. Ruddle 992-8283

METAL FORMING SECTION

The objective of the research program in the Metal Forming Laboratory is to develop metalworking facilities, processing techniques and information, and databases to improve Canadian capability and competitiveness in industrial production of flat-rolled and shaped steels, non-ferrous products, and advanced metallic and composite materials.

DEVELOPMENT OF METAL WORKING TECHNOLOGIES

Metalworking research in this laboratory includes experimental development and evaluation of thermomechanical processing schedules for plate, strip and sheet, measurement and prediction of rolling parameters, measurement of base flow stress data and constitutive modelling of flow behaviour, finite element modelling of metalworking processes, and experimental fabrication of advanced materials. The research is subdivided into the following technological categories:

1. Rolling mill processing technology.
2. Formability and processing of sheet steels.
3. Near net shape forming.
4. Manufacturing technology in metalworking.
5. Processing and fabrication of advanced materials.

New activities projected the metalworking technologies program into an international role. A steel-mill engineer from Sumitomo Metal Industries, Japan, completed a year of resident study and research in the Metal Forming Laboratory which provided a mutually beneficial technical exchange for both Sumitomo and PMRL. A committee of the American Iron and Steel Institute has selected the cam plastometer facility, based on a test data survey, for its development of base flow stress data for steel bar and strip rolling schedules. PMRL is providing leadership in the organization of international symposia presenting the state-of-the-art in metalworking technologies: "Computer modelling of metal fabrication processes" (Ottawa, May 1986), "Accelerated cooling of rolled steel" (Winnipeg, August 1987), and "Physical simulation of metal forming processes" (Ottawa, May 1988).

ROLLING MILL PROCESSING TECHNOLOGY

Rolling mill processes are being developed for modern high quality steel plate, strip and shapes based on the optimum utilization of Canadian industrial facilities. New technological opportunities are demonstrated by designing schedules incorporating thermomechanical processing and in-line controlled cooling and by modelling and simulation of rolling deformation.

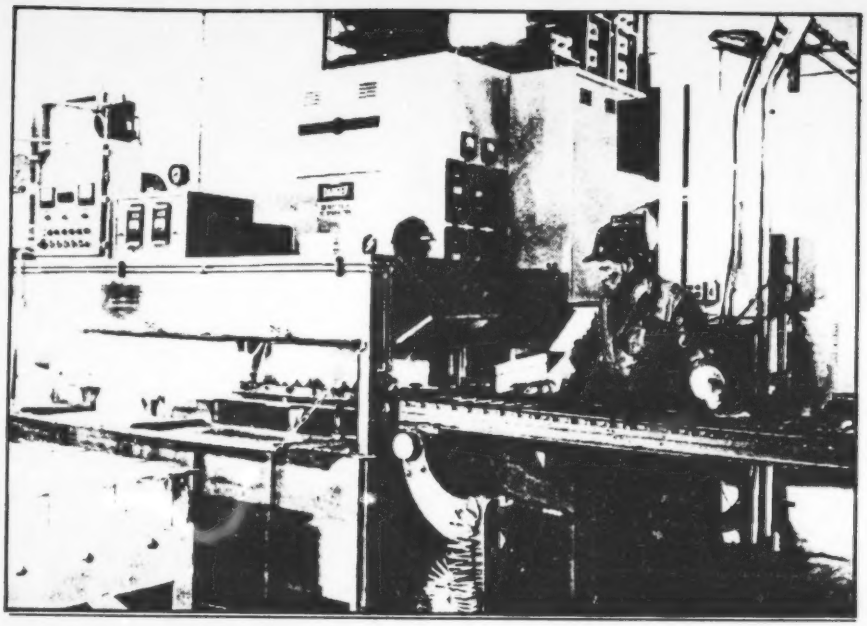
Research aimed to give steel industry an insight into control of rolling processes was continued in mathematical modelling of the mechanical, thermal and metallurgical aspects of the process. The modelling accomplishments were as follows:

Accurate prediction of average grain size developed in controlled recrystallization rolling of plain carbon and microalloyed steels was achieved by adaptation of mathematical models. This prediction capability has potential use in on-line control of rolling pass reduction and prediction of metallurgical behaviour of the rolled product, particularly in hot-strip processes.

Evaluation of two theoretical models and an empirical model for predicting rolling force and torque using pilot-scale plate rolling data for a range of microalloyed steel compositions demonstrated that the empirical model has superior predictive accuracy. This model also can be easily computed and updated and, therefore, is potentially adaptable to on-line control and optimization of reduction schedules in automated rolling processes.

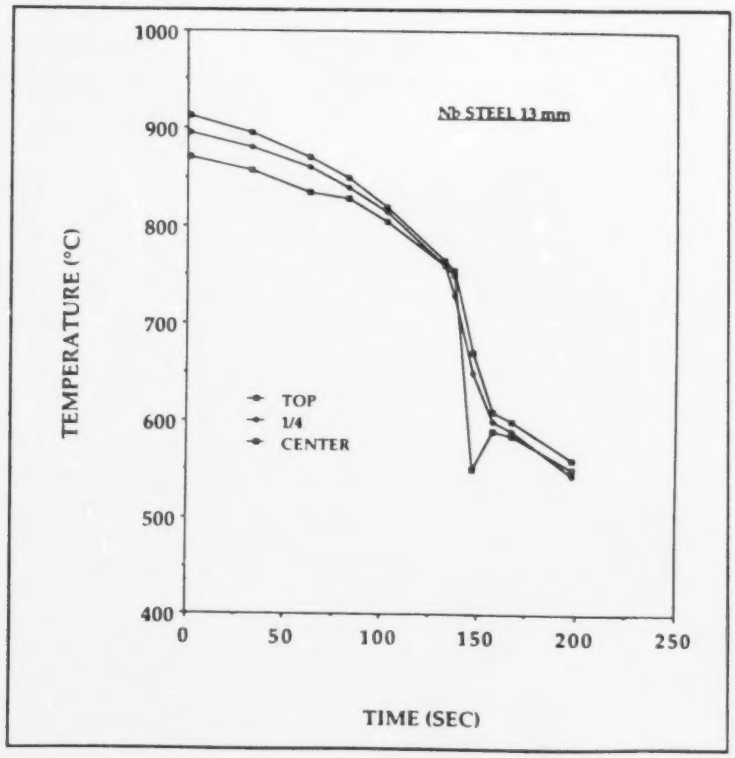
A finite element code developed for prediction of coupled thermal/mechanical formings behaviour was advanced to the stage of application to improved industrial rolling processes. Validation and proposed technological use of the code are described in the near-net-shape forming research.

The operation of the pilot-scale on-line accelerated cooling (OLAC) system was improved and experimental process development for high-strength, notch-tough, weldable steel plates was initiated. System modifications included improved control of water filtering and flow, and extension of the range of water spray rates from full quench down to 3°C/s to enable controlled cooling of rolled thicknesses from 21 mm down to 2 mm strip gauge. The system is being applied initially to demonstrate the potential benefits of OLAC technology to Canadian steel plate producers (Algoma, IPSCO, Stelco). Experimental testing focussed on development of thermal uniformity of cooling through the plate thickness and of corresponding through-thickness



Transfer of hot-rolled plate from rolling mill to on-line accelerated cooling (OLAC) water-spray system.

uniformity and refinement of microstructure produced in the suppressed austenite-ferrite transformation cycle. Cooling treatments on Nb and Nb-V microalloyed linepipe-grade plates are being developed on the basis of continuous-cooling-transformation dilatometry data, and will be evaluated in terms of the plate microstructural and mechanical properties.

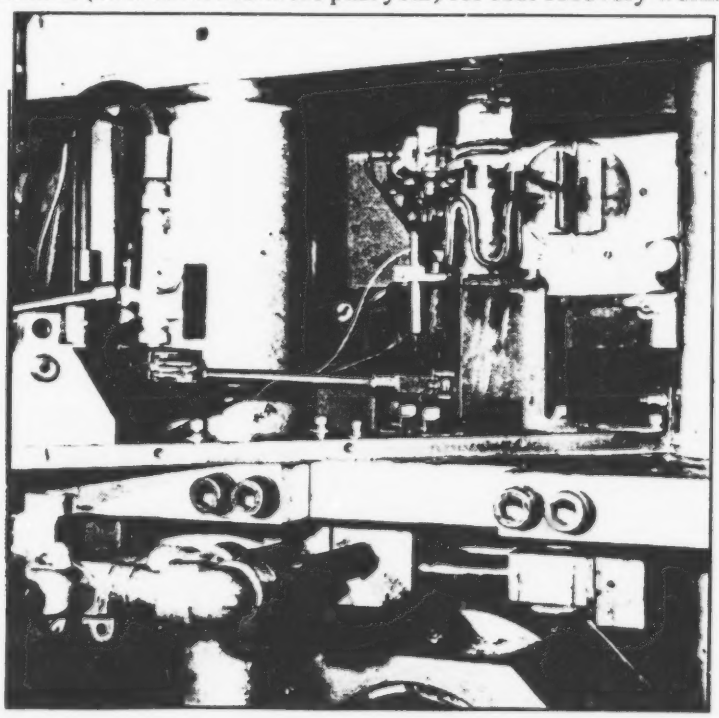


Temperature profiles versus time at centre, 1/4 thickness and near top surface of 13 mm thick steel plate during accelerated cooling from 770°C to 600°C.

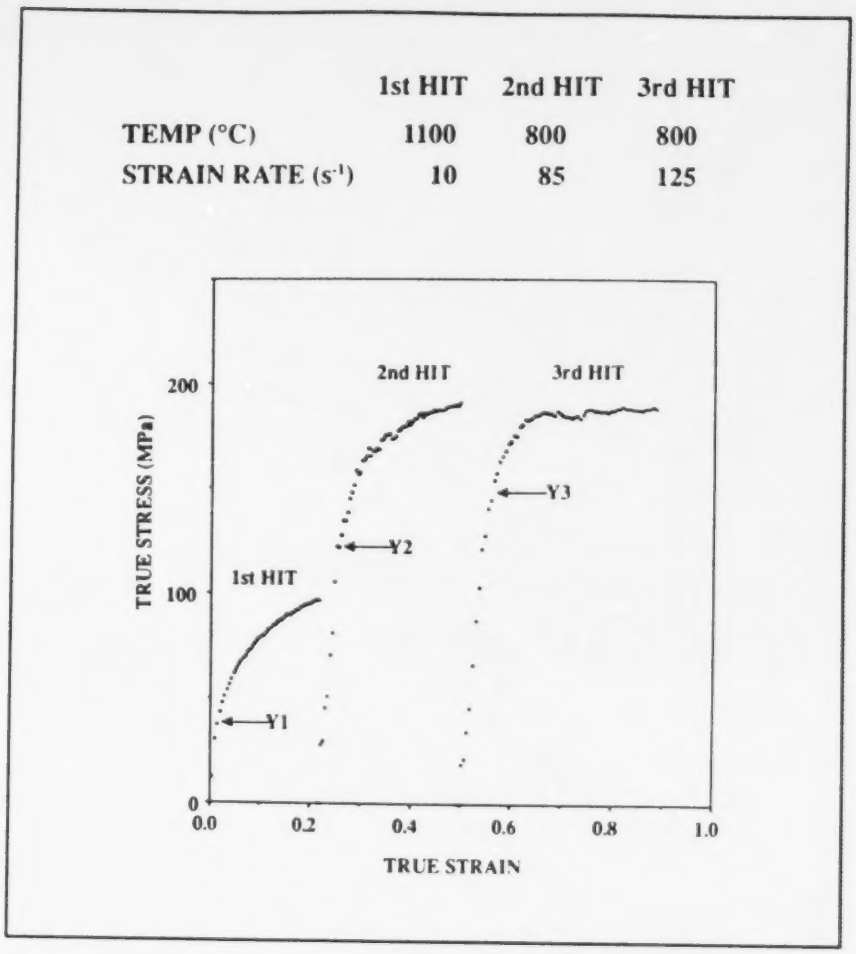
Hot-strip rolling of plain-carbon and microalloyed steels was simulated both in cam plastometer and pilot-reversing mill tests. Correlation of the simulation results with industrial rolled hot-strip showed that, if austenite grain size is independent of strain rate and interpass time, simulation of the industrial reduction temperature schedule in the reversing mill can produce steel strip of similar microstructural and tensile properties as in the industrial tandem strip-mill. This simulation capability was developed in preparation for new industry-co-operative projects on simulating and modelling of Canadian hot-strip mills, and for new cost-recovery projects requiring flow stress and microstructural data for hot-strip process development and control.

Methods of applying plastometer flow stress data to prediction of roll forces were developed further. The use of simple models of softening and of strain retained during interpass times permitted equally accurate force prediction using flow stress data from single-hit tests, obtained previously with data from multiple-hit tests.

Essential to the development of hot-strip processing was a further upgrade of the cam plastometer. The improvements permit rapid in-situ heating (up to 1300°C) of compression test specimens, high frequency recording of high strain-rate test data and immediate quenching of the tested specimens. The advanced design plastometer is now a unique facility, capable of simulating hot-strip rolling deformation sequences with interhit times down to 0.2-0.5 s and at strain rates up to 300 s^{-1}. Its significance to industry is demonstrated by an increasing demand (25% of its use in the past year) for cost-recovery work.



View of in-situ induction heating of steel compression test specimen on the cam plastometer.



Stress-strain data for three compression hits in a cam-plastometer simulation of one roughing deformation and two finishing deformations in a hot-strip rolling sequence. Y1, Y2, Y3 are the 0.2% yield stresses.

Use of the pilot-scale rolling mill extended to processing of experimental steels for other internal and external developmental projects on automotive, rail, marine and energy-recovery materials. Extensive cost-recovery work included processing of a wide range of ferrous and non-ferrous metal products for large and small industry, universities and government agencies. Co-operative developments with industry and university groups began on mathematical and metallurgical modelling of a major hot-strip steel mill (UBC and Stelco) and co-operation continued on a process development for microalloyed steel seamless tube (McGill University and Algoma Steel). Rolled steel billets were produced for share-funded industrial developments of automotive spring and tire-bead wire steels (Stelco).

Contracted research continued on the study of the effects of microalloying additions of niobium and/or boron on the hot-working characteristics of ultra-low-carbon bainitic steel compositions for linepipe grades. The current phase of the work, investigating precipitation phenomena, has shown that the addition of boron accelerates the precipitation of niobium carbonitrides in the

strained austenite. Non-equilibrium segregation of boron and niobium induced at the grain boundaries in the deformed austenite was revealed, by autoradiographic and electron-microscopic examinations, as being responsible for retardation of boundary movement in the recrystallization which follows hot deformation. Similar examination of the deformed austenite under precipitation conditions is intended to determine how the boron-niobium segregation effects more rapid carbonitride formation.

A second research contract has continued to study the hot-workability of strand-cast microalloyed steels. The initial part of the study has developed and applied hot-tensile tests to characterize the hot-ductility properties of a commercial strand-cast grade 350 MPa steel over a range of critical test conditions. The conditions under which dynamic recrystallization sustains ductile behaviour to larger strains without initiation of failure in the test piece were identified. Testing techniques and information developed in the initial work are being extended to determine systematically the effects of carbon and nitrogen (the basic carbonitride-forming elements) on the hot ductility of a cast niobium-microalloyed steel.

FORMABILITY AND PROCESSING OF SHEET STEELS

Research in the formability and processing of sheet steels is to advance the understanding of the influence of processing, composition and microstructure on the mechanical properties and formability of sheet steels (continuous-annealed plain carbon, high-strength low-alloy, dual phase and galvanized) to contribute to the improved and consistent quality of the industrial product.

Work was completed on the influence of the thermal cycle in a Sendzimir-type galvanizing line on the properties of aluminum-killed drawing-quality (AKDQ) steel. The results show that good drawability, as assessed by plastic anisotropy and crystallographic texture, depends upon a high coiling temperature. For example, the plastic anisotropy ratio (r-value) after coiling at 538°C was about 1.0, whereas after coiling at 735°C it was about 1.7. Final mechanical and formability properties were relatively tolerant of variations in hold time and heat-up rate in the recrystallization thermal cycle. The improved properties resulting from a high coiling temperature were correlated with the development of aluminum nitride precipitates and the carbon content of the ferrite, both of which influence the evolution of texture. These results answer problems identified by the Canadian steel sheet producers (Algoma, Dofasco, Sidbec-Dosco, Stelco).

A FORTRAN computer program developed earlier was modified extensively to be more "user-friendly". Tests were carried out on six distinctly different grades of steel, supplied by Dofasco and Stelco, to validate the program. It is designed to determine the r-value from sheet tensile tests for in-plant quality control of formability.

Completed contract research clearly defined the differences in forming behaviour, mainly frictional effects, resulting from the galvanized coating of steel sheet compared with non-coated sheet. The final report was distributed to the Canadian galvanized sheet sheet producers (Dofasco, Stelco).

NEAR NET SHAPE FORMING

Metal forming techniques that reduce materials and energy usage are being developed through analyses of the interplay of metal flow and microstructural development.

The main research effort concentrated on validation of the thermal-mechanical coupled non-linear finite element code which was developed in this project to predict plastic flow and heat transfer in metal forming processes. Theoretical validation of the code was completed and, with experimental validation continuing, the code was advanced to the capability of modelling thermomechanical behaviour in hot rolling processes. Implementation began on technology transfer of the code to analyses of Canadian industrial rolling processes. Proposed analyses initially apply to process improvements required in a major hot-strip mill (Stelco) and in a Steckel hot-plate mill (IPSCO). A DEC Micro Vax digital processing system was established for further code development for on-line control of forming processes.

To bridge the existing technology gap among the different disciplines required in modelling of metal forming processes, an international symposium on "Computer modelling of fabrication processes and constitutive behaviour of metals" was held at CANMET, Ottawa in May 1986. The symposium successfully fulfilled its objective with 80 registered attendees participating. The printed proceedings are scheduled for publication in 1987.

A contracted research study of new forgeability criteria assessed the use of the fiducial grating technique for micro-strain measurements at and near the tips of cracks formed in forgeability tests. The fiducial technique was found effective for micro-analysis of internal crack formation. New criteria developed in the study will be useful for defining the limiting conditions for industrial forging processes. Reports of the contract work were issued.

MANUFACTURING TECHNOLOGY IN METALWORKING

Pilot-scale facilities are being established and research and development are being conducted to apply modern knowledge of metal flow behaviour to processes such as extrusion, swaging and wire drawing, and to provide direct technology assistance to Canadian manufacturers.

Establishment of pilot-scale forming facilities of rod/wire products has not progressed because funds did not materialize from capital replacement proposals. However existing rolling facilities were applied to provide starting billet stock for industry-funded projects on automotive spring steel and tire-bead wire development at Stelco Inc. Also, an existing small-scale wire drawer produced short lengths of steel wire for Welding Institute of Canada research on composition effects in welding steel consumables. This was accomplished by cold drawing after a series of swaging reductions and annealing treatments of machined-rod starting stock

PROCESSING AND FABRICATION OF ADVANCED MATERIALS

Facilities and expertise are being developed to process and form advanced materials such as rapidly solidified alloys, bi-metals and metal-matrix composites.

Based on a survey of requirements and techniques to extrude rapidly solidified materials, the decision was taken to develop tooling and in-situ heating for precise-control extrusion of experimental quantities of material on an existing 100/200-ton vertical press. Preforms for extrusion, 3.5 cm diameter by 9 cm length, will be compacted at ambient temperature on an existing 500-ton vertical press. The refit design of the extrusion press will provide for heating capability of 500°C maximum, operation at 273 ksi (1880 MPa) pressure and extrusion ratios of 6, 13 and 24. After the necessary modifications and retooling have been completed, the refitted presses will be applied initially to fabrication of rapidly solidified copper alloy, using ribbon or powder stock, in a co-operative marine alloy development with DREA. This work will be integrated with other Divisional projects on rapid-solidification material production, testing and characterization.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Metal Forming Section are underlined)

Baragar, D.L.
"The high temperature, high strain rate behavior of a plain carbon and an HSLA Steel"; J of Mechanical Working Tech.; 12; 201; 1987.

Baragar, D.L.
"The evaluation of hot rolling models using Cam Plastometer flow stress data"; 28th Mechanical Working and Steel Processing Conf.; Pittsburgh, PA; Oct. 1986; Iron and Steel Society of AIME; 161;.1986.

Biner, S.B. and Too, J.J.M.
"Analysis of cracks in welded T-Joints"; Proc. of Fatigue Prevention and Design; Ed. J.T. Barnby; Amsterdam, The Netherlands; April 1986; 272; 1986.

Collins, L.E., Knight, R.F., Ruddle, G.E., and Boyd, J.D.
"Laboratory development of accelerated cooling of microalloyed plate steels"; Accelerated Cooling of Steel; Ed. P.D. Southwick; Pittsburgh, PA; Aug. 1985; TMS-AIME; 261; 1986.

Galvani, C., Crawley, A.F., L'Espérance, G., Holt, R., and Cousineau, E.
"Precipation and textural effects in rapid annealing of cold-rolled aluminum killed steels"; Proc. 28th Mechanical Working and Steel Processing Conference; Pittsburg, PA; Oct. 1986; Iron and Steel Society of AIME; 287; 1986.

Ozsoy, I.C., Ruddle, G.E. and Crawley, A.F.
"A drafting model for hot plate rolling to minimise processing costs and crop losses"; Seventh International Symposium on Measurement and Control; Eds. A.T. Dinibutin, M.H. Hamza and A. Kuzucu; Istanbul,Turkey; July 1985; 195; 1986.

Ruddle, G.E., and Baragar, D.L.
"Grain refinement by recrystallization hot-rolling to achieve high strength and notch toughness in microalloyed steel plate"; Seventh International Symposium on theStrength of Metals and Alloys (ICSMA 7); Eds. H.J. McQueen et. al.; Montreal, PQ; Aug., 1985; Pergamon Press; 2091; 1986.

AVAILABLE PMRL REPORTS

On line accelerated cooling system for the PMRL experimental hot rolling mill. G. Smelsky	**PMRL 86-48 (INT)**
Metal forming operations and the 900 ton PMRL extrusion press. G. Smelsky	**PMRL 86-81 (INT)**

PMRL 86-77(OP-J) Precipitation and textural effects in rapid annealing of cold rolled aluminum killed sheet. C.A. Galvani and A.F. Crawley

PMRL 85-55(J) Evaluation of hot-rolling models using Cam Plastometer flow stress data. D.L. Baragar

One cost recovery report was completed by the Metal Forming Section in FY 86/87.

PRESENTATIONS

(Presenting authors from the Metal Forming Section underlined)

Baragar, D.L.
"The evaluation of hot rolling models using Cam Plastometer flow stress data"; 28th Mechanical Working and Steel Processing Conference; Pittsburgh, PA; Oct. 1986.

Biner, S.B., Too, J.J.M.
"Spring-element method and its application to fracture analysis; (Presented by a rapporteur) Sym. on Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa, Ont.; May .

Biner, S.B., Harnaes, J., Too, J.J.M.
"Analysis of axisymmetric extrusion with numerical and model material techniques"; Sym. on Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa; May 15-16, 1986.

Crawley, A.F. and Galvani, C.
"Aspects of r-value development in continuously annealed sheet"; Fall Meeting of North American Deep Drawing Research Group; Dearborn, MI; October 1986.

Galvani, C., Crawley, A.F., L'Espérance, G., Holt, R., and Cousineau, E.
"Precipitation and textural effects in rapid annealing of cold rolled aluminum killed steel"; 28th Mechanical Working and Steel Processing Conference; Pittsburgh, PA; Oct.1986.

Galvani, C., Crawley, A. L'Espérance, G., Holt, R., and Cousineau, E.
"Precipitation and textural effects in rapid annealing of cold rolled aluminum killed sheet"; (Poster Presentation) Canadian Metal Physics Conf.; Kingston, Ont.; June 1986.

Ozsoy, I.C., Ruddle, G.E., Dogan, B., and Crawley, A.F.
"Optimisation modelling of hot rolling practices applied to a Ti-V micro-alloyed steel"; Mathematical Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa, Ont.; May 1986.

Ruddle, G.E. and Ozsoy, I.C.
"Modelling of roll force and torque for control of flat hot-rolling processes"; CIM 25th Annual Conference of Metallurgists; Toronto, Ont.; Aug. 1986.

Ruddle, G.E. and Crawley, A.F.
"Evaluation of through-thickness gradients of temperature, strain and flow stress in hot-rolling deformation of plain-carbon and microalloyed steel"; Annual Meeting of the Metallurgical Society of AIME; Denver, CO; Feb. 1987.

Too, J.J.M.
"A coupled thermal/ mechanical model for the prediction of deformation behavior of rolling processes";(Presented by a rapporteur) Sym. on Modelling of Fabrication Processes and Constitutive Behaviour of Metals; Ottawa, Ont.; May 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J.J.M. Too	Dr. R.W. Smith & Mr. J.W. Shi, Dept. of Metallurgical Engineering Queen's University.	Study of forgeability based on local strain and grain structure effects under varied deformation rates and temperature.

SA/LO	Performer	Project
A.F. Crawley	McMaster University	Influence of friction on the prediction of formability for galvanised low and high strength steels.
G.E. Ruddle	Prof. M.G. Akben, McGill University	Effect of aluminum on recrystallization and precipitation in Mo and Nb steels.
G.E.Ruddle	Prof. J.J. Jonas, McGill University	Behaviour of microalloyed steels under industrial rolling conditions.
G.E. Ruddle	Prof. M.G. Akben, McGill University	Simulation of hot working (controlled rolling) of continuous-cast HSLA steels.
G.E. Ruddle	Prof. J.J. Jonas, McGill University	Effect of boron on precipitation and recrystallization kinetics in hot deformation of titanium-niobium microalloyed steels.

COMPLETED CONTRACT RESEARCH REPORTS

To determine the influence of fricton on the prediction of formability and press shop performance for galvanized low and high strength steel.
Performer: McMaster University
Scientific Authority A.F. Crawley

Nondestructive Testing Section

Section Head **V.L. Caron** **996-4480**

NONDESTRUCTIVE TESTING SECTION

The activities of the Nondestructive Testing (NDT) Section encompass both the long-established procedures involved in the national certification of NDT personnel in Canada and the development of NDT technology.

The R&D component focusses on both conventional and advanced technologies and reflects the greater level of sophistication that now characterizes NDT contributions to process and product quality control. All projects take into account their potential commercial applications and seek early industrial participation. Other projects are targeted for energy transportation and recovery, especially in the off shore and Arctic.

CERTIFICATION OF NONDESTRUCTIVE TESTING PERSONNEL

The objective of this project is to certify non-destructive testing (NDT) Personnel on a national basis. The strong growth of NDT reflects national concerns for (a) public safety through the need for structural integrity of engineering structures (nuclear plants, pipelines, etc.); (b) product quality and liability; (c) conservation of resources, and (d) productivity increase. The certification of qualified NDT personnel must be strictly controlled and be unaffected by adverse influences or pressures. In Canada, there is a general consensus of opinion that the certification of NDT personnel is a function best performed in the public sector.

NDT personnel are being certified in the usual five methods and to a three-level system in accordance with CGSB standards. Since 1960 more than 10000 certificates have been issued including 700 in 1986-87. A new practical test centre was established at the Southern Alberta Institute of Technology, Calgary. Renewal of certification is now based on a three-year term instead of the one-year term. Certification and renewal fees underwent a major increase of 1987.

PMRL continued assuming the responsibility of the inter-national secretariat of ISO TC135-SC7 on NDT personnel certification. SC7 work progressed to the Draft Proposal stage and the document was registered by ISO Central Secretariat. Membership in SC7 now includes 33 countries and thus reflects the rapidly increasing worldwide interest in that activity.

NONDESTRUCTIVE TESTING TECHNOLOGY DEVELOPMENT

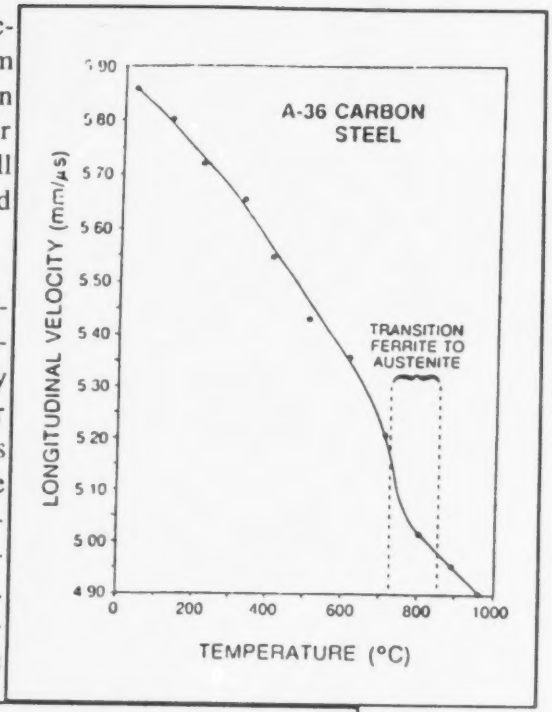
Thrusts in this activity were: defect detection and characterization; on-line process monitoring and materials property assessment. Work continued in the area of ultrasonic inspection and characterization using optical and laser methods. This technology will enable samples to be inspected at elevated temperatures and will be amenable to the inspection of awkward shapes. A high-powered short-pulse laser is used to generate ultrasound. The displacement of the ultrasound reflected from a flaw at the surface of the sample is than detected by a second laser and an optical interferometer. Ongoing work aims at making the technology sufficiently sensitive for laboratory and industrial applications. Two receiver systems are being developed. (a) One is based on optical heterodyning (Michelson interferometer) and has a broad ultrasonic frequency response suitable for laboratory measurements. (b) The other is based on the confocal Fabry-Perot interferometer which demodulates the Doppler shift produced by ultrasound. This system is immune to peturbations, such as vibrations, fumes and noises, depends less critically on optical alignment, and has good sensitivity on rough surfaces which makes it suitable for industrial inspection.

The optical heterodyne receiver was further improved to a near-commercial stage. A system based on the same principle was used to characterize various aluminum/ceramic composites at elevated temperatures. The Fabry-Perot system was applied to the detection of artificial defects on plain carbon steel and to ultrasonic measurements up to 1000°C in conditions similar to those encountered in industry. Such a technique provide a means to characterize steel at elevated temperatures to monitor microstructural changes. This system was also applied to the detection of artificial delaminations and impact damage defects in graphite-epoxy composites an area where there is presently a strong interest. Technology transfer and commercialization of those two technologies will be pursued by a Canadian company which was selected from a thorough search across Canada.

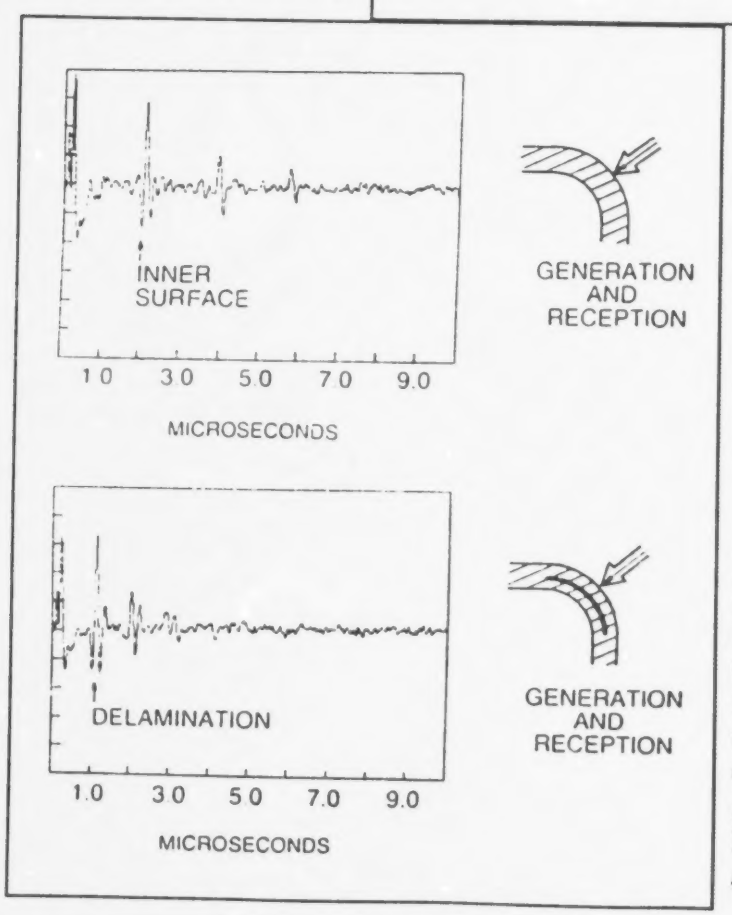
In collaboration with Techno-Scientific Co, a programme was written to reconstruct a flaw inside a metal part, using an angled ultrasonic beam. Experimental data has been collected on simulated flaws. The image was displayed in a three dimensional perspective. For near-surface reflections. A

method using the phase spectrum of a Fourier transform of the time signal has been used to determine their depth. The results agree will with time correlation method used by previous workers.

A technique has been developed for carrying out ultrasound reflection tomography using transmitter-receiver transducers. Travel times along extremum paths are used for image reconstruction instead of those obtainable from diffraction theory. It has been shown that applying beam divergence angle



Ultrasonic velocity of a plain carbon steel versus temperature measured with the Fabry-Perot laser-ultrasonic inspection system in conditions similar to those encountered in industry.

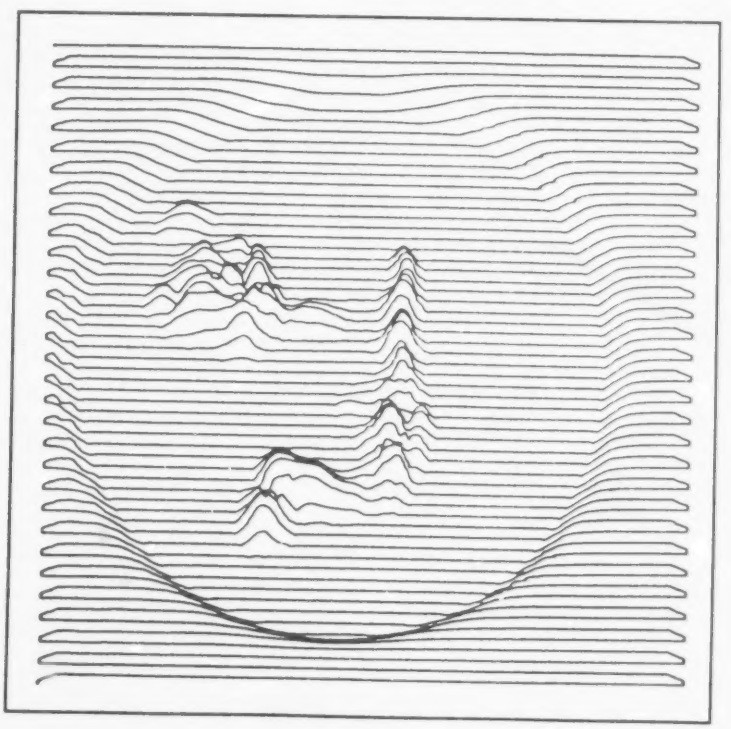


Inspection of a corner-shaped graphite-epoxy specimen by laser ultrasonics. (Graphite-epoxy composites have an all black strongly absorbing surface which make them difficult specimens for optical detection of ultrasound) Above: Zone free of delamination. Below: Delamination introduced at mid-thickness.

limitation enhances the clarity of the image and also saves a lot of computer time. Convolution back projection and threshold operation can also help to improve the image.

An acoustic emission prototype to monitor defect formation during welding underwent further testing in CANMET laboratories and industrial conditions using both hardware and software developed by the contractor (Tektrend Intl.) Using test results, methods were developed to apply pattern recognition to acoustic emissions source identification in order to reduce background and process noise and to provide a more powerful signal location and acquisition programme. The report concluded to its ability to identify and classify process noises was demonstrated as was these of acoustic emission as a routine inspection method. As for technology transfer, the contractor has entered into a commercial agreement with a large USA firm to market system worldwide as well as its Intelligent Classifier Engineering Package (ICE-PAK) signal processing software.

Another acoustic emission based project has entailed a co-operative effort to assess its application in proof testing compressed gas tube trailers in order to achieve a higher sensitivity level and to lower the costs of such regulatory testing which normally uses hydrostatic testing. Results obtained in a first phase would indicate its potential although proof test pressure of 150% rather than 110% service pressure may be needed to obtain more reliable results.



An ultrasonic image of hydrogen disbonding in a weld overlay surface layer of a petrochemical reactor vessel.

Manitoba Research Council, with the industrial support of Abex Industries, evaluated vibration response technique to assess soundness in cast components by measuring the first natural frequency directly from the response spectrum. The case study involved a typical steel casting containing shrinkage, porosity add inclusions. Temperature changes and dimensional tolerances caused differences on vibration response and these were measured. Nevertheless the corrected values of decreasing natural frequency resulting from the presence of defects showed good correlation with radiographic quality.

Monitoring pipelines in service principally relies on magnetic flux leakage tools to detect and measure defects. Also magnetic measurements can lead to monitor bending stresses. This university-based project was to provide basic data to an industrial project included three parts: studies of basic magnetization and magnetostriction effects: studies of stress due to gas line pressure on magnetic flux leakage signals; and the design of a pipeline bending stress monitoring test rig. Field data showed that bending stress produces detectable changes in the magnetic fields which is measured at selected burial depths above large pipelines. Such a monitoring test rig was reported to be a feasible and relatively economical proposition.

STRUCTURAL INTEGRITY MONITORING OF OFFSHORE STRUCTURES

Disregarding potential global monitoring through acoustic methods which are under development, the in-service inspection of offshore tubular structures involves two approaches: detecting and locating defects followed by sizing both length and depth and its growth. Magnetic particle remains the most used technique for detecting a surface crack and also provides a length estimate. Ascan ultrasonics and ACDP techniques are used mainly for sizing measurements.

Under contract to Artec Canada, a computer-controlled two-dimensional acoustic array using electronic switching will be designed and constructed for imaging defects. The amplitude and phase delay of signal applying to each element of the array will be controlled such that the focal length of the ultrasonic beam can be varied and the angle of incidence of the beam can be steered. Design of the phased array assembly, amplifier, timing and interface circuits and electronics have been completed. The control and data acquisition software preliminary design has also been performed.

The technology of eddy current testing should provide a valid alternative to magnetic particle method besides being amenable to rapid scanning and automation to reliably detect new surface breaking cracks underwater.

Collecting and interpreting test results should be available as surface readouts. Evaluation of the method should measure crack length as accurately as magnetic particle inspection. Rapid scanning would separate the diver from the inspector role. The system should tolerate the presence of paints and protective coatings. Varied progress with respect to evaluation achieved during the past year.

Focal Marine started work on basic aspects towards developing optic fibres stress/strains sensors for application to large scale engineering works such as encountered in geotechnical and structural engineering (ex: leg loads on a jackup drilling unit) ie pressures at an ice-structure interface, offshore pipelines, etc.

Optic fibre technology would circumvent various limitations of conventional strain gauges. A microbending type sensor was selected for development starting with a 1cm x 1cm gauge area. The design of an experimental apparatus was completed and work done on a proper fiber configuration to measure various types of strain prior to characterizing the sensor.

Work was performed by Nova Corporation to develop an inspection design and procedures for selecting transducers and inspect girth welds in on-shore and off-shore pipelines. Results have showed that specialized ultrasonic beams were successful in the weldroot region but less so, in the cap and body regions which will necessitate further investigation.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Nondestructive Testing Section are underlined)

Louis, G., Lepoutre, F. and Monchalin, J.-P.
"Influence of condenser microphones on phase measurements in photoacoustics at low pressure"; Canadian J. of Physics; 64; 1111; 1986.

Mak, D.K.
"Correction of beam entry point for the pitch-catch technique in ultrasonic testing"; CSNDT Journal; 7; 22; 1986.

Mak, D.K.
"Computer polar plots of intensity of scattered waves from a rigid cylinder"; Acoustics Letters; 10; 1; 1986.

Monchalin, J.-P. and Héon, R.
"Laser ultrasonic generation and optical detection with a confocal Fabry-Pérot interferometer"; Material Evaluation; 44 ; 1231; 1986.

Monchalin, J.-P.
"Optical detection of ultrasound "; IEEE Trans. on Sonics, Ultrasonics Ferroelectrics and Frequency Control; UFFC-33; 485; 1986.

Monchalin,J.-P.
"Detection at a distance of laser-generated ultrasound using a confocal Fabry-Pérot interferometer"; Canadian J. of Physics; 64; 1320; 1986.

Monchalin, J.-P., Bussière, J.F. and Bertrand, L.
"Thermal-wave vignetting and standing-wave effects in the infrared detection of ultrasonic absorbtion"; Canadian J. of Physics; 64; 1059; 1986.

Monchalin, J.-P., Héon , R. and Muzak, N.
"Evaluation of ultrasonic inspection procedures by field mapping with an optical probe"; Canadian Metallurgical Quarterly; 25:3; 247; 1986.

Monchalin, J.-P.
"Ultrasonic industrial materials characterization by laser generation and optical detection "12th Int. Congress on Acoustics; Toronto, Ontario; July 1986; Paper G3-6; 1986.

Piche, L., Champagne, B., and Monchalin, J.-P.
"Laser-ultrasonic measurement of elastic constants of composites"; Material Evaluation; 45; 74; 1987.

AVAILABLE PMRL REPORTS

Locating in three-dimensional space using double transducers. D. K. Mak	**ERP/PMRL 84-54 (J)**
Determination of grain size, hysteresis constant and scattering factor of polycrystalline material using ultrasonic attenuation. D.K. Mak	**PMRL 86-2 (J)**
Computer polar plots of intensity of scattered waves from a rigid cylinder. D.K. Mak	**PMRL 86-49 (J)**
Acoustical imaging with mode-converted waves. D.K. Mak	**PMRL 86-49 (J)**

PMRL 86-52 (J)	A three ellipsoid intersection method for ultrasonic testing. D.K. Mak
PMRL 86-58 (J)	Focusing effect of an unfocused transducer on point scatterers. D.K. Mak
PMRL 86-35 (OP-J)	Ultrasonic reflection tomography with a transmitter-receiver system. D.K. Mak
PMRL 86-84 (OP-J)	Evaluation of size and orientation of scatterers by ultrasonic spectroscopy. D.K. Mak
PMRL 86-83 (OP-J)	Near surface flaw positioning using ultrasonic phase information. D.K. Mak

PRESENTATIONS

(Presenting authors from the Nondestructive Testing Section underlined)

Mak, D.K.
"Ultrasonic reflection tomography with a transmitter-receiver system"; 15th symposium on Acoustical Imaging; Halifax; July 1986.

Mak, D.K., Macecek, M. and Kovacs, A.
"Ultrasonic defect visualization in a metal block"; (Poster Presentation) 15th Symposium on Acoustical Imaging; Halifax; July 1986.

Monchalin J.-P.
"Ultrasonic industrial materials characterisation by laser generation and optical detection", 12th Int. Congress on Acoustics; Toronto, Ont.; July 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
V. Caron	Tektrend International Inc.	Development of on-line acoustic emission monitoring for welding thick walled vessels.

SA/LO	Performer	Project
V. Caron	Manitoba Research Council.	Identification of defects in cast steel components by vibration analysis.
V. Caron	Tektrend International Inc.	Accoustic emission testing of compressed gas tube trailers.
V. Caron	UK/HARWELL United Kingdom Atomic Energy Authority.	Offshore inspection R&D services.
D.K. Mak	Techno. Scientific	Modification of the automated ultrasonic scanning system for acoustical imaging.
D.K. Mak	Nova, An Alberta Corporation.	Selection of ultrasonic transducers for girth weld inspection.
D.K. Mak	Artec Canada Limited	Design and construction of a computer controlled two dimensional acoustic array for imaging defects in offshore structure weldments.
D.K. Mak	Techno Scientific	Automated ultrasonic flaw imaging System

COMPLETED CONTRACT RESEARCH REPORTS

Continuation of investigation of the effects of mechanical stress on the magnetic properties of pipeline steels for application in pipeline stress monitoring.

Performer: Queen's University.
Scientific Authority D.K. Mak

Welding Section

Section Head J.T. McGrath 992-3916

WELDING SECTION

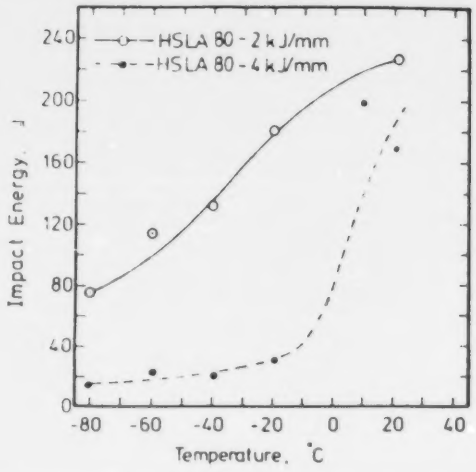
The objectives of the welding technology program are twofold: a) to develop a data base for the assessment of welding processes relevant to major CANMET materials research b) to evaluate the microstructure and mechanical properties of welded structures.

The output of the work is directed toward EMR programs, and those of other Federal Government departments, concerned with the material selection, fabrication and safe operation of welded engineering structures. In parallel the welding program seeks to assist the Canadian fabrication industry adopt new technology and specifications for welding fabrication and repair. Highlights of the work carried out within four projects are summarized.

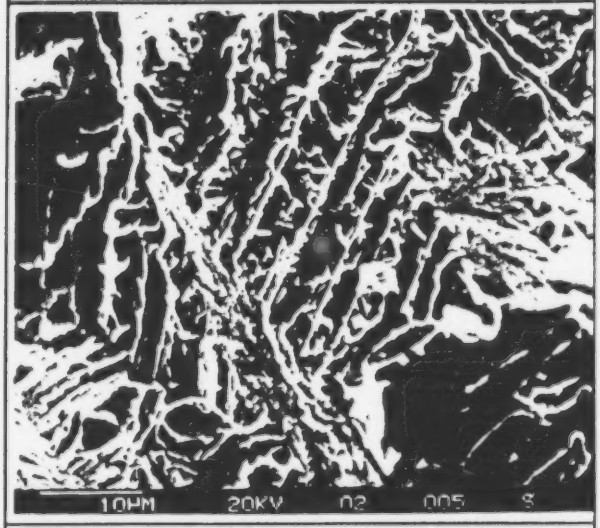
WELDABILITY OF PLATE STEEL FOR MARINE APPLICATION

Welding procedures are being evaluated and the strength and notch toughness properties of steel weldments for arctic ships and naval submarines are being documented in this project. In the past year most of the work has been concerned with an evaluation of the weldability of various high-strength steel weldments for submarine fabrication. This work, which is partially funded by the Department of National Defence, directly supports their program for the acquisition of a submarine fleet.Current studies are directed at evaluating the weldability of HY 100, HSLA 80 and HSLA 100 steels. In the submerged-arc welding of HY 100 steel, particular procedures have been detailed i.e. control of preheat, interpass and post heat temperatures, to avoid hydrogen cracking in the weld metal. The HSLA 80 steel, which is a replacement for HY 80, achieved the targeted notch toughness properties in the heat-affected zone i.e. 47 J at -500C, in welds prepared at a heat input of 2 kJ/mm. There was a sharp drop in toughness for a heat input of 4 kJ/mm. The preliminary work on HSLA 100 steel indicated that good toughness in the heat-affected zone can be obtained at heat inputs < 2 kJ/mm.

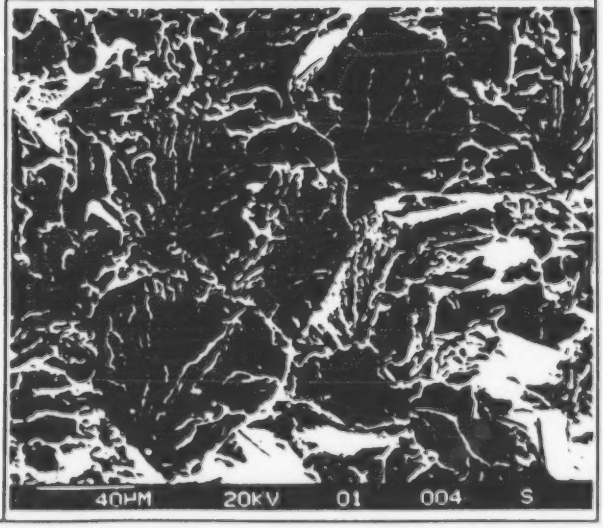
Notch toughness properties of the heat-affected zone of welds in high strength HSLA80 steel. Superior toughness was found at an energy input of 2 kJ/mm.



Scanning electron micrograph of fractured surface of 2 kJ/mm HSLA80 heat-affected zone specimen. Fine fracture steps are indicative of good notch toughness.



Scanning electron micrograph of fractured 4 kJ/mm HSLA80 heat-affected zone specimen. Coarse cleavage facet size indicates low notch toughness.



DEVELOPMENT OF NEW WELDING PROCESSES

New welding processes are being evaluated for the fabrication and repair of energy technology related structures such as pressure vessels, offshore structures and pipelines.

Welding procedures for the submerged-arc narrow-gap process have been developed in-house for thick-section 2.25 Cr - 1Mo steel which yield optimum weld composition and microstructure to meet the required reactor vessel weld-metal mechanical properties. Contract work on narrow-gap welding focussed on in-shop welding procedures for joining 200 mm thick-section pressure-vessel steels.

The experimental part of Phase I of the national program on weld-overlay disbonding has been completed. Some of the factors contributing to disbonding of stainless steel overlay from 2.25 Cr - 1 Mo base metal have been identified. Specifically, the effect of cooling rate after exposure to high temperature, high pressure hydrogen was most prominent. Slow cooling reduces the buildup of hydrogen at the overlay/base metal interface thus lowering the temperature for disbonding.

The work on quantitative correlation of welding parameters has resulted in the development of empirical equations which relate weld process parameters to weld features such as nugget size, penetration and melting rate of the submerged-arc and gas-metal-arc processes.

A strategy for the development and evaluation of welding repair procedures for petrochemical-plant welded structures is being established. This will be a cooperative program with designers, fabricators and operators of petrochemical plants.

The new program on laser welding has begun with a study of the factors controlling the laser welding of a range of aluminum alloys. The NRC 2.5 kW continuous CO_2 laser is being used to investigate the effects of shielding gas dynamics, joint preheat and surface preparation on welding rate and quality.

WELDING TECHNOLOGY FOR OFFSHORE STRUCTURES

The fracture properties of welded joints for offshore structures are being evaluated and welding consumables are being developed to optimize weld properties.

In the in-house program, the evaluation of crack-tip opening displacement (CTOD) and Charpy V-notch (CVN) fracture properties of welds made from the flux cored, shielded metal arc and submerged arc processes employing over 40 welding consumables has been completed. Correlations of the CTOD/CVN data are being derived statistically for design/regulatory usage. Investigation of the effects of heat input and nickel content on the M-A phase produced in shielded metal arc welds are continuing.

Work continues in three external contracts leading to the future commercial development of welding consumables for optimum weld fracture toughness properties. This work is guided by an industrial task force whose commercial interests in consumable development parallel the regulatory need for base-line data. The contract has been completed on the evaluation of the potential of the pulsed gas-metal-arc welding process for the all-position, mechanized and automated welding of offshore oil and gas installations and arctic vessels. Commercial exploitation of the results of this cost-shared work has been initiated.

THERMAL/MECHANICAL SIMULATION OF METALLURGICAL PROCESSES

Using the Gleeble thermal mechanical simulator, some of the factors controlling metallurgical processes such as continuous-casting, welding and hot rolling have been investigated

In the area of continuous casting, a cooperative program with Canadian steel companies evaluated the ductility of steels that were melted and resolidified in the Gleeble 1500. The effects of tellurium and magnesium on sulfide shape control are being investigated.

The program on the evaluation of heat-affected-zone microstructure and notch toughness properties for a selection of Canadian and Japanese steels has been completed. This work, in collaboration with the Japanese National Research Institute of Metals, showed that the Japanese steels had superior heat-affected zone properties with typical Charpy impact values of 65 J at -500C after a 10 kJ/mm heat input simulation. The best Canadian steel had 30 J at -500C after a 3 kJ/mm weld simulation. External contracts are underway on (a) modelling of weld thermal cycles, grain growth and precipitate dissolution in the heat-affected zone and (b) identification of precipitates in real-weld and simulated heat-affected zones for a range of offshore steels.

PUBLICATIONS

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Welding Section are underlined)

Braid, J.E.M.
"Offshore structure materials research: ongoing programmes of CANMET's Physical Metallurgy Research Laboratories"; Marine Engineering Digest; 6:1; 23; 1986.

Braid, J.E.M. and McGrath, J.T.
"The influence of microstructure and strain on the toughness of welded joints in structural steels for offshore applications"; Canadian Metallurgical Quarterly; 25:2; 131 1986.

Braid, J.E.M., and Gianetto, J.A.,
The effects of PWHT on thetoughness of shielded metal arc weld metals for use in Canadian offshore structure fabrication"; Welding for Challenging Environments; Ed: Welding Institute of Canada, Toronto, Ontario; Oct. 1985; Pergamon Press; 145; 1986.

Braid, J.E.M., and Gianetto, J.A.
"The effects of PWHT on the toughness of shielded metal arc weld metals for use in Canadian offshore structure fabrication"; International Institute of Welding Annual Meeting; Tokyo, Japan;.July 1986; IIW DOC IIA-684-86, IX-1385-86, X-1101-86; 1986.

Chandel, R.S.
"Prediction of weld metal dilution from SAW parameters"; Welding Review; 6:1; 45; 1987.

Chandel, R.S., Orr, R.F., Gianetto, J.A., McGrath, J.T., and Wright, B.
"Some factors affecting the mechanical properties of submerged-arc narrow-gap welds"; Welding for Challenging Environments; Ed: Welding Institute of Canada, Toronto, Ontario; Oct. 1985; Pergamon Press; 97; 1986.

Chandel, R.S., and Malik, L.M.
"Relationship between wire feed speed and SAW parameters"; Welding for Challenging Environments; Ed: Welding Institute of Canada, Toronto, Ontario; Oct. 1985; Pergamon Press; 245; 1986.

Chandel, R.S., and Bala, S.R.
"Effect of welding parameters and groove angle on the soundness of root beads deposited by the SAW process"; Advances in Welding Science and Technology ; Ed. S.A. David; Gotlinburg, Tenn.; May 1986; ASM; 379;1986.

Hoey, G.R., Ramsingh, R.R., and Bowker, J.T.
"Dependence of stress corrosion cracking of parent, heat-affected zone, and weld metal of HSLA line-pipe steel on potential"; Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods; Eds. G.C. Moran and P. Labine; American Society for Testing and Materials, Philadelphia, PA; ASTM STP 908; 386; 1986.

McGrath, J.T.
"The microstructive and mechanical properties of low alloy Cr/Mo steel weld metals"; International Institute of Welding Annual Meeting; Tokyo, Japan;.July 1986; IIW DOC IXG-326-86;.1986.

Romharyi, K Krishnadev, M.R., McDonald, R., Bowker, J.T. and McGrath, J.T.
"Comparison of simulated HAZ microstructure and toughness for two high strength steels"; International Institute of Welding Annual Meeting; Tokyo, Japan;.July 1986; IIW DOC ILX-1419-86; 1986.

Shehata, M.T., Chandel, R.S., Braid, J.E.M., and McGrath, J.T.
"Characterization of non metallic inclusions in weld metals"; Microstructural Science 14; 65;.1986.

AVAILABLE PMRL REPORTS

PMRL 85-39 (TR) Laboratory simulation of flash-butt welding of rail (Interim report). D.M. Fegredo, L.E. Collins, J.T. Bowker

PMRL 86-25 (TR) Prediction of wire feed speed from AC submerged arc welding. R.S. Chandel

PMRL 86-53 (TR) Microstructure and mechanical properties of low-alloy Cr/Mo steel weld metals. J.T. McGrath

A report on the 1986 annual assembly of IIW and visits to two research laboratories, Japan, July 1-20, 1986. J.E.M. Braid	**PMRL 86-72 (INT)**
The development of welding procedures for the joining of high-strength HY100 steel J.T. McGrath, J.A. Gianetto and R.F. Orr	**PMRL 86-67 (INT)**
Effect of welding parameters and groove angle on the soundness of root beads. R.S. Chandel and S.R. Bala	**PMRL 85-32 (OP-J)**
Mathematical modelling of melting rates during SAW welding. R.S. Chandel	**PMRL 86-5 (J)**
Relationship between SAW parameters and weld bead size. R.S. Chandel and S.R. Bala	**PMRL 86-38(J)**
Some factors affecting the notch-toughness of high strength HY80 weldments. J.T. McGrath, J.A. Gianetto, R.F. Orr and M.W. Letts	**PMRL 86-50 (J)**
Effect of submerged arc process variables on penetration and its prediction. R.S. Chandel, S.R. Bala and L. Malik	**PMRL 86-79 (J)**
Microstructure/mechanical property relationships in thick section C-Mn narrow gap welds. J.T. McGrath, R.S. Chandel, R.F. Orr and J.A. Gianetto	**PMRL 86-86 (J)**
Effects of process variables on the wire melting rate of the GMAW process and its prediction. R.S. Chandel	**PMRL 86-87 (J)**
Some factors affecting the structural integrity of weldments in heavy wall reactor vessels. J.T. McGrath, R.S. Chandel, R.F. Orr and J.A. Gianetto	**PMRL 86-95 (J)**

PRESENTATIONS

(Presenting authors from the Welding Section underlined)

Bowker, J.T.
"Heat affected zone microstructure and toughness of a range of TMCP steels"; Nippon Steel II Fundamental Research Laboratories, Tokyo, Japan; July 1986.

Bowker, J.T.
"Thermal simulation using resistance heating and induction heating systems"; National Research Institute for Metals; July 1986.

Braid, J.E.M., and Gianetto, J.A.
"The effects of PWHT on the toughness of shielded metal arc weld metals for use in Canadian offshore structure fabrication"; Annual Assembly of the International Institute of Welding; Tokyo, Japan; July , 1986.

Braid, J.E.M.
"Toughness of weld metal for Canadian offshore structure fabrication"; Workshop on Steel Welding Research; Welding Institute of Canada, Oakville, Ont.; April 1986.

Braid, J.E.M.
Effect of heat input and stress relief temperature on the microstructure of SMA weld metals; 25th Conf. of Metallurgists; Toronto, Ont; Aug. 1986

Chandel, R.S., McGrath, J.T., Orr, R.F. and Gianetto, J.A.
Microstructure and mechanical properties of SAW-NG welds in SA 516 Gr-70 pressure vessel steel"; Conf. of Metallurgists; Toronto, Ont.; Aug. 1986.

Chandel, R.S., Bala, S.R.
"Effect of welding parameters and groove angle on the soundness of root beads deposited by the SAW process"; Trends in Welding Research; Gotlinburg, Tenn.; May 1986.

Krishnadev, M.R., McGrath, J.T., Bowker, J.T., Dionne S. and Laasraoui, A.
HAZ microstructure and toughness of preciptation strengthened HSLA steels and conventional HY-grade steels"; International Symposium on Welding Metallurgy of structural steels; Denver, Colorado, Feb. 1987.

McGrath, J.T.
"Notch toughness properties in HAZ of HY80 Weldments"; Workshop on Steel Welding Research; Welding Institute of Canada, Oakville, Ont.; April 1986.

McGrath, J.T., Chandel, R.S., Orr, R.F., and Gianetto, J.A.
"Some factors affecting the structural integrity of weldments in heavy wall reactor vessels"; Atlantic Section Conf. of the National Assoc. of Corrosion Engineers; Halifax, NS; Nov. 1986.

Patchett, B.M., McGrath, J.T., Orr, R.F., Gianetto, J.A., and Bicknell, A.C.
"Control of microstructure and mechanical properties in SAW and GMAW weld metals"; International Symposium on Welding Metallurgy of Structural Steels; Denver, Colorado, Feb. 1987.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J. Bowker	Carleton University	Prediction of weld thermal cycles, HAZ hardness, grain growth and precipitation.
J. Bowker	AMCA International	Evaluation of HAZ and weld metal toughness in selected steels-Phase I.
J.E.M. Braid	The Welding Institute (U.K.)	HAZ toughness of thick section steels.
J.E.M. Braid	Canadian Liquid Air	Inclusion effects on weld metal toughness in SMAW low hydrogen deposits.
J.E.M. Braid	AMCA International	Evaluation of HAZ and weld metal toughness in selected steels.- Phases I & II.
J.E.M. Braid	Nova, An Alberta Corp.	Pulsed gas metal arc welding of thick section steels for low temperature applications.
J.E.M. Braid	Technical University of Nova Scotia	Surface tension and slag metal reaction effects in FCAW consumables.
R.S. Chandel	Babcock and Wilcox Canada	Development of stainless steel cladding technology

SA/LO	Performer	Project
R.S. Chandel	AMCA International	Relationship between process parameters and WFS for arc welding processes.
R.S. Chandel	Carleton University	Prediction of weld thermal cycles, HAZ hardness, grain growth and precipitation.
R.S. Chandel	Falconbridge Ltd.	Repair and reclaimation technology of cast iron mining equipment.
R.S. Chandel	AMCA International	GMAW 2061
R.S. Chandel	Welding Institute of Canada	GMAW 2156
J.T. McGrath	Stelco	Evaluation and development of the GMAW/SAW process
J.T. McGrath	Welding Institute of Canada.	Evaluation of weld overlay disbonding.
J.T. McGrath	Welding Institute of Canada.	Study on equivalence of stress relief treatments.
J.T. McGrath	Fluor Canada	C/Mn welding consumables for arctic, offshore and petrochemical application.
J.T. McGrath	University of Toronto	Characterization of precipitates in the weld HAZ for a range of offshore needs.
J.T. McGrath	Babcock and Wilcox	Evaluation of factors controlling toughness of narrow gap welds.
J.T. McGrath	University of Alberta	Preparation and evaluation of weldments employing narrow gap and strip overlay welding processes.

COMPLETED CONTRACT RESEARCH REPORTS

Develop and evaluate the Gas metal arc welding/submerged arc welding (GMAW/SAW) process for improved weld properties.
Performer: Stelco.
Scientific Authority J.T. McGrath

Study to improve solidification cracking resistance of submerged arc weldmetal.
Performer: Welding Institute ofCanada.
Scientific Authority J.T. McGrath

Evaluation of flux-cored arc welding consumables for offshore and arctic structure fabrication.
Performer: AMCA International.
Scientific Authority J.T. McGrath

CTOD testing of MAW and SAW specimens
Performer: R.B. Lazor & M.H. Irvine of the Welding Institute.
Scientific Authority J.E.M. Braid

Evaluation of heat affected zone and weld Metal toughness in selected steels
Performer: AMCA International Ltd.

Scientific Authority J.E.M. Braid

Pulsed gas metal arc welding of thick-section steels for low temperature applications.
Performer: NOVA.
Scientific Authority J.E.M. Braid

Relationship between process parameters and wire feed speed for arc welding processes.
Performer: AMCA International Ltd.
Scientific Authority R.S. Chandel

TECHNOLOGY EXCHANGE

TECHNOLOGY EXCHANGE

Partial List of companies, government agencies, universities, and research organizations with which PMRL has been associated during FY 86-87

INDUSTRY

A

A-1 Steel Foundry	Saskatoon, Sask.
Abex Corp.	Joliette, Que.
Abex Corp.	Mawa, N.J.
ACADZ Inc.	Montreal, Que.
ACG Technology Ltd.	Mississauga, Ont.
Adjeleian Allen Rubeli	Toronto, Ont.
AIMCO	St. Catharines, Ont.
Alberta Energy Co. Ltd.	Edmonton, Alta.
Alberta Rockwool Corp.	Calgary, Alta.
Alcan Canada Ltd.	Kingston, Ont.
Alcan Research Centre	Arvida, Que.
Algoma Steel	Sault Ste. Marie, Ont.
Alloy Foundry	Merrickville, Ont.
Alpha Cast Inc.	Whitewater Wis.
AMAX	Michigan, Conn.
AMAX	Golden, CO.
AMCA International	Montreal, Que.
AMCA International	Ottawa, Ont.
Ancast	Winnipeg, Man.
Arctec Canada Ltd.	Kanata, Ont.
Ardiem Inc. Corp.	Vancouver, B.C.
Asbestos Institute	Montreal, Que.
Associated Foundry	Surrey, B.C.
Astromet	Cincinnati, Ohio
Atlas, Steel	Welland, Ont.
Atlas, Steel	Varennes, Que.
Aurora Metals Division	Montgomery, Ill.
Avesta Stainless Inc.	

B

Babcock & Wilcox	Cambridge, Ont.
Badene, L. Associates	Willowdale, Ont.
Battelle	Columbus, Ohio
Bay Bronze	Winnipeg, Man.
Beaumart Ltée.	Contrecoeur, Que.
Beaver Dental Products	Morrisburg, Ont.
Beaver Delta Machinery	Guelph
Belgen Foundry	Drummondville, Que.
Bell Northern Research	Ottawa, Ont.
Bethlehem Steel Corp.	Pittsburgh, Pa.
Bethlehem Steel Corp.	Bethlehem, Pa.
BHP Iron and Steel	Wollongong, Australia
Blaw - Knox	Chicago, Ill.
Blanchard Foundry	Saskatoon, Sask.
Brampton Foundries	Brampton, Ont.
Bow Valley Industries	Calgary, Alta.
Boart Canada	Toronto, Ont.
Brazloy Metals Inc.	Don Mills, Ont.
Bow Valley Offshore Limited Partnership	Halifax, N.S.
British American Bank Note Inc.	Ottawa, Ont.
British Steel Corp.	Middlesborough, U.K.
Brom Machine & Foundry Co., Ltd.	Winona, Minnesota
Brown Boggs Ltd.	Hamilton, Ont.
B and T MacFarlane Ltd.	Ottawa, Ont.
Burnstein Castings Ltd.	St. Catharines, Ont.

C

Cambridge Brass	Cambridge, Ont.
Canadian Bronze Co.	Winnipeg, Man.
Canadian General Electric	Peterborough, Ont.
Canadian Industries Ltd. (CIL)	Montreal, Que.
Canadian Insulation Service	Montreal, Que.
Canadian Liquid Air Ltd.	Montreal, Que.
Canadian Pacific Railways	Montreal, Que.
Canadian Pacific Research Labs.	Montreal, Que.
Canadian Stone Marine Ltd.	Iberville, Que.
Canadian Tungsten	Vancouver, B.C.
Cancarb Ltd.	
Canmount Investment Corp.	
Canertech Inc.	Winnipeg, Man.
Canron Foundry	Hamilton, Ont.
Canron Inc.	Rexdale, Ont.
Canterra Energy	Calgary, Alta.
Caproco Ltd.	Edmonton, Alta.
Carborundum Corp.	Bethlehem, Pa.
CBI Industries Inc.	Oak Brook, Ill.
Chadrien Ltd.	Ottawa, Ont.
Chevron Corporation	Richmond, Ca.
Chinook Fuel Innovations Ltd.	Calgary, Alta.
Chromasco Ltd.	Haley, Ont.
Climax Molybdenum Co	Golden, Colo.
C and M Engineering	Calgary, Alta.
Cominco	Sheridan Park, Ont.
Combustion Engineering - Superheater Ltd.	Ottawa, Ont.
Copper Development Assoc.	New York, N.Y.
Corrosion Control	Toronto, Ont.
Corrosion Service Co.	Toronto, Ont.
COSIPA Steel	Brazil, Ont.
Crane Ltd.	Medicine Hat, Alta.
CRAMCO Solder Alloys	Scarborough, Ont.
Crowe Foundry	London, Ont.
Creusot-Loire	France
Custom Aluminum	Cambridge, Ont.

D

Darling Bros. Ltd.	Montreal, Que.
Date Industries	Ayr, Ont.
Davie Shipbuilding	Lauzon, Que.
Davis Engineering	Ottawa, Ont.
Dayton Malleable Iron Co.	Dayton, Ohio
Dayton-Walther Foundry	Guelph, Ont.
de Havilland Aircraft	Toronto, Ont.
Delfab-Hallteck	Halifax, N.S.
Delta Group Consultants	Ottawa, Ont.
Devel. Tech.	Saskatoon, Sask.
Det norske Veritas	Calgary, Ont.
Dofasco	Hamilton, Ont.
Dome Petroleum Ltd.	Calgary, Alta.
Dominion Bridge	Ottawa, Ont.
Dominion Bridge	Edmonton, Alta.
Dominion Engineering Works	Montreal, Que.
Domtar Chemicals	Toronto, Ont.
Dow Chemical	Midland, MI
Duffers Associates	Troy, N.Y.
Dynawest Projects Ltd.	Calgary, Alta.

E

Eastern Steel Castings	Hawesbury, Ont.
Eastview Engineering	Hull, Que.
Eaton-Yale	Chatham, Ont.
E.B. Eddy Forest Products Ltd.	Ottawa, Ont.
ECS Power Systems	Ottawa, Ont.
Eirich Canada	Maple, Ont.
Electromec	Quebec City, Que.
Elkem Inc.	Niagara Falls, N.Y.
Engineering Products of Canada Ltd.	Boucherville, Que.
Engineers India Ltd.	New Delhi, India
Enterprise Foundry	Sackville, N.B.
ESAB	Sweden
ESAB	Norway
ESAB	Montreal, Que.
Esco Corp.	Portland, Oregon
Esco Corp.	Port Coquitlam, B.C.
Esco Corp.	Port Hope, Ont.
Esso Chemical, Canada	Calgary, Alta.
Esso Resources	Calgary, Alta.
Exeltar Ltd.	Bedford, Que.
Exxon Production Research Company	Houston, Tx.

F

Fahramet Industries Ltd.	Orillia, Ont.
Falconbridge Nickel Mines Ltd.	Toronto, Ont.
Ferrco	Whitby, Ont.
Fleetwood Metal Ind.	Tilbury, Ont.
Fluor Canada	Calgary, Alta.
Fonderie Antique	Athabasca, Que.
Fonderie Poitras	L'Islettville, Que.
Fonderie Romuald	St. Romuald, Que.
Fonderie Saguenay	Chicoutimi, Que.
Fonderie Industriel	Laforo Quebec, Que.
Fondremy	Chambly, Que.
Foote Mineral Corp.	Chicago, Ill.
Ford Motor Co.	Deerborn, MI.
Forintek Canada Corp.	Ottawa, Ont.
Foster Wheeler	St. Catherines, Ont.

G

Galtaco	Guelph, Ont.
Gamma Foundries Ltd.	Richmond Hill, Ont.
Garrett Canada Ltd.	Hamilton, Ont.
General Casting Corp.	Milwaukee, Wis.
General Motors	Ste. Catharines, Ont.
Global Canatom	Cambridge, Ont.
Goodkey Weedmark & Associates	Ottawa, Ont.
GSW	Hamilton, Ont.
Gulf Canada Ltd.	Calgary, Alta.
Gulf Canada Resources Co. Ltd.	Calgary, Alta.

H

Habitation Nordique	Quebec City, Que.
Haley Industries	Haley Junction, Ont.
Hall and Stavert Ltd.	Charlottetown, P.E.I.
Hamilton Foundry	Hamilton, Ont.
Hanson Material Engineering	Edmonton, Alta.
Hatch Associates	Toronto, Ont.
Hayes Stuart Inc.	Montreal, Que.
Heritage Foundry	Winkler, Man.
High Vacuum Systems Inc.	Brampton, Ont.
Highveld Steel and Vanadium Corp. Ltd.	London, England
Highland Foundry	Surrey, B.C.
Hirst Research Centre	London, England
Holmes Foundry	Sarnia, Ont.
Hooper & Angus Ltd.	Toronto, Ont.
Howmet Thermatech	Bouchervill, Que.
Husky Oil	Calgary, Alta.
Husky Oil	Lloydminster, B.C.

I

IMP Foundry Ltd.	Dartmouth, N.S.
Imperial Oil Ltd.	Toronto, Ont.
INCO	Toronto, Ont.
Industries USP	Lennoxville, Que.
Ingersoll-Rand Can. Ltd.	Cambridge, Ont.
Inproheat Ltd.	Vancouver, B.C.
International Harvester	Hamilton, Ont.
International Harvester	Chicago, Ill.
International Malleable Ltd.	Guelph, Ont.
International Paint Co.	Montreal, Que.
Interprovincial Steel & Pipe Corp., Ltd.	Regina, Sask.
Intersteel Consultants Ltd.	Willowdale, Ont.
Itres Research Ltd.	Calgary, Alta.
ITT	Grinnell
ITT Aimco Ltd.	St. Catherines, Ont.
Ivaco	L'Original, Ont.

J

Jamaica Manufacturing Co. Ltd.	Prescott, Ont.
Jarrell-Ash	Waltham, Mass.
Jenkins Canada Inc.	Lachine, Que.
J.M. Asbestos Ltd.	Asbestos, Que.
Johnson-Matthey	Brantford, Ont.
Jones Fortier Advisors Ltd.	Pittsburg, PA

K

Kanmet Foundry	Cambridge, Ont.
Kashima Steel Works	Kashima, Japan
Kawasaki Steel Corp.	Chiba, Japan
Kelly Foundry and Machinery	Elkins, Va.

Kelsey Hayes Ltd.	Woodstock, Ont.
Kentucky Centre for Mining and Mineral Research	Lexington, Ky.
Kidd Creek Mines Ltd.	Edison, N.J.
Krupp-Quakertown	Cambridge, Ont.
Kulp Foundry	Stroudsburg, Pa.
Kwicki	Calgary, Alta.

L

La Fonderie Thetford	Thetford Mines, Que.
Lake Ontario Steel Corp.	Whitby, Ont.
Leaver, E.W.	Willowdale, Ont.
Les Fonderies MAC Inc.	Boucherville, Que.
Lethbridge Iron Works	Lethbridge, Alta.
Levelton, B.H. and Associates	Vancouver, B.C.
Limpact Industries Ltd.	Cobourg, Ont.
Lincoln Electric	Toronto, Ont.
Little, A.D. and Associates	Cambridge, Mass.
Lloyd's Registry	London, U.K.
Lloyd's Registry	Montreal, Que.
Lobo and Associates	Paris, Ont.
Lumonics Inc.	Ottawa, Ont.
Lusjne Chain Co.	Sweden

M

Magaloy Foundry	Stratford, Ont.
Magdalen Silica	Montreal, Que.
Mainland Manufacturing	Vancouver, B.C.
Maritime Steel foundry	New Glasgow, N.S.
Mathews, Jas.	Milton, Ont.
Marex Welding Products Ltd.	Walthem Cross, U.K.
Masdon Corp.	Calgary, Alta.
Massey Ferguson	Brantford, Ont.
McLean Foundry	Brantford, Ont.
Metallurgical Consultants, Inc.	Houston, Tx.
Metals and Alloys Inc.	Toronto, Ont.
Minexpert Inc.	Montreal, Que.
Mitel Corp.	Kanata, Ont.
Mitsubishi	Canada
Mobil Oil	Halifax, N.S.
Modern Castings	Des Plaines, Ill.
Monarch Industries Ltd.	Winkler, Man.
Mondel Eng.	Mississauga, Ont.
Mueller Industries	St. Jérome, Que.

N

Niagara Bronze	Niagara Falls, Ont.
Nippon Steel	Kimitsu, Japan
Nomis Computer Systems Corp.	Ottawa, Ont.
Nonferrous Alloy Castings Ltd.	Mississauga, Ont.
Noranda Mines, Ltd.	Murdockville, Que.
Noranda Research Centre	Pointe Claire, Que.
Norsk Hydro	Oslo, Norway
Northern Telecom Canada Ltd.	Ottawa, Ont.
Nordco	St. John's, Nfld.
Norwood Foundry	Regina, Sask.
NOVA - An Alberta Corp.	Calgary, Alta.
Nutech Precision Metals	Amprior, Ont.
Nyes Foundry	Vancouver, B.C.

O

OCL Industrial Materials	Vancouver, B.C.
ODC/OILFAB	St. John's, Nfld.
Oilfab Haltech Ltd.	Dartmouth, N.S.
Olan Industries	Lake Stevens, Wa.
Omark Ltd.	Cambridge, Ont.
Optotek	Ottawa, Ont.
Orangeville Foundry	Orangeville, Ont.
Ortec Corp.	Oakridge, TEN.

P

Pacific Enercon	Grandforks, B.C.
Packer Engineering	Napierville, Ill.
Partec - Lavalin	Toronto, Ont.
Pergamon Press, Canada	Willowdale, Ont.
PetroCan	Montreal, Que.
PetroCan Products Ltd.	Toronto, Ont..
Pfizer	Montreal, Que.
Pfizer International	New York, N.Y.
Philips Electronics	Canada
Plant Adjustment Bureau Ltd	Moncton, N.B.
Port Arthur Shipbuilding Co.	Thunderbay, Ont.
Port Weller Dry Dock Ltd.	St. Catharines, Ont.
Pratt and Whitney Canada Ltd.	Longueuil, Que.

Price Waterhouse Assoc.	Toronto, Ont.
Proto Manufacturing	Windsor, Ont.
Prudential Steel Ltd.	Edmonton, Alta.

Q

Quatar General Petroleum Corp.	Quatar
Quatic Chemicals	Cambridge, Ont.
Quebec Iron and Titanium	Sorel, Que.
Quebec Metal Powders	Sorel, Que.

R

Rahn Metals	North Bay, Ont.
Reynolds Aluminum	Richmond, Va.
Ridge Foundry	San Leandro, Ca.
Robar Industry	Surrey, B.C.
Robertson, Jas. Foundry	Toronto, Ont.
Robertson-Nickerson	Ottawa, Ont.
Rockwell International	Troy, MI
Rolls Royce Canada Ltd.	Montreal, Que.
Roxul Corp.	Milton, Ont.
Russell & Co. Ltd.	Ottawa, Ont.

S

Servimet Inc.	Tracy, Que.
Shell Canada Resources	Calgary, Alta.
Sherritt-Gordon Mines Limited	Fort Sask., Alta.
Sherritt-Gordon Research Centre	Fort Sask., Alta.
Sidbec-Dosco	Contrecoeur, Que.
Siemens AG	Karlsruhre, FDR
Sinteris Canada Inc.	Blenheim, Ont.
SNC Inc.	Montreal, Que.
Sonco Steel Tubing	Brampton, Ont.
Spar Aerospace	Toronto, Ont.
St. John Foundry	St. John, N.B.
St. John Shipbuilding and Dry Dock Co.	St. John, N.B.
St. John's Marine	St. John's, Nfld.
St. Romvald Fonderie	Quebec City, Que.
Standard Induction Casting	Windsor, Ont.
Stainless Foundry & Engineering Corp	Milwaukee, Wis.
Stanton Foundry	St. Hubert, Que.
Stanton Pipes Ltd.	Hamilton, Ont.
Steel Company of Canada (STELCO)	Burlington, Ont.
Steel Company of Canda	Hamilton, Ont.
Steel Engine Products Ltd.	Liverpool, N.S.
Steelflow Inc.	Okotoks, Alta.
Stepsan	Toronto, Ont.
Stittsville Foundry	Stittsville, Ont.
Sumitomo Steel Company	Houston, Tx.
Sumitomo Metals	Japan .
SUNCOR	Sarnia, Ont.
Sydney Steel Corporation (SYSCO)	N. Sydney, N.S.
Syncrude Canada	Fort McMurray, Alta.

T

Tallman Bronze	Burlington, Ont.
Techno Scientific	Downsview, Ont.
Tektrend Int'l Ltd.	Lachute, Que.
Tekrad	Quebec City, Que.
Teledyne Cast Products	California
Terminal City Foundry	Vancouver, B.C.
Tonawanda Coke Corp.	Tonawanda, N.Y.
TransCanada Pipelines	Toronto, Ont.
Transportation Development Centre	Montreal, Que.
Trudeau, P.	Ottawa, Ont.
Turbine Components	Brantford, Conn.

U

Union Carbide	Montreal, Que.
Union Carbide	Toronto, Ont.
Union Gas	Chatham, Ont.
Union Screen Plate	Lennoxville, Que.
United States Steel Corp.	Monroeville, Pa.

V

Vada Industries Ltd.	Okotoks, Alta.
Versatile Vickers	Montreal, Que.
Via Rail Canada Inc.	Montreal, Que.
Viatek Ltd.	Calgary, Alta.

Vicinary Chain Co.	Spain
Vickers Canada	Montreal, Que.
Vickers Ruwolf Adams Foundry	Victoria, Aus.
Victoria Machining Depot	Victoria, B.C.

W

Wellington Foundry	Wellington, Ont.
Wells Foundry	London, Ont.
West Coast Transmission	Vancouver, B.C.
Western Foundry	Wingham, Ont.
Westinghouse Research and Development Centre	Pittsburgh, Pa..
Wilson Brass foundry	Scarborough, Ont.
Wolfedale Eng. Ltd.	Mississauga, Ont.
World University Service	Ottawa, Ont.
Wotherspoon Foundry	Oakville, Ont.

Y

York Barbell Co. Ltd.	Oakville, Ont.

Z

Zalev Bros.	Windsor, Ont.
Zenon Environmental	Burlington, Ont.

CANADIAN FEDERAL GOVERNMENT

A

Agriculture Canada	Ottawa, Ont.
Atomic Energy of Canada	Chalk River, Ont.
Atomic Energy Control Board	Ottawa, Ont.

C

Canada Customs	Ottawa, Ont.
Canadian Broadcasting Corp., Northern Services - Radio	Ottawa, Ont.
Canadian Coast Guard St. John, N.B. Dartmouth, N.S.	Ottawa, Ont.
Canadian International Development Agency	Ottawa, Ont.
Canadian National Marine	St. John's, Nfld.
Canadian National Railways	Montreal, Que.
Canadian Oil and Gas Lands Administration	Ottawa, Ont.
Canadian Pacific Railways	Montreal, Que.
Canadian Patents and Development Ltd.	Ottawa, Ont.
Canadian Transport Commission	Ottawa, Ont.
CANARCTIC Shipping Co.	Vancouver, B.C.
Consumer and Corporate Affairs	Ottawa, Ont.
Correctional Services	Ottawa, Ont.

D

Defense Research Est. Atlantic	Halifax, N.S.
Defense Research Est. Pacific	Esquimalt, B.C.

E

Eldorado Nuclear	Ottawa, Ont.
Export Development Corp.	Ottawa, Ont.
External Affairs	Ottawa, Ont.

I

IMRI	Boucherville, Que.
Industry, Trade & Commerce	Ottawa, Ont.
International Development Research Centre	Ottawa, Ont.

L

Library of Parliament	Ottawa, Ont.

N

National Aeronautical Establishment	Ottawa, Ont.
National Defence, Dept. of	Ottawa, Ont.
National Defence, Dept. of	Halifax, N.S.
National Energy Board	Ottawa, Ont.
National Museums of Canada	Ottawa, Ont.
National Research Council	Ottawa, Ont.
National Research Council IMRI	Montreal, Que.
National Research Council-Tribology Laboratory	Vancouver, B.C.

P

Petro Canada	Calgary, Alta.
Public Archives	Ottawa, Ont.
Public Works Canada	Ottawa, Ont.

R

Revenue Canada - Customs and Excise	Ottawa, Ont.
Regional Economic Expansion Dept.	Halifax, N.S.
Royal Canadian Mint	Ottawa, Ont.
Royal Canadian Mounted Police	Ottawa, Ont.

S

Science & Technology - Ministry of State	Ottawa, Ont.
Solicitor General of Canada - Inmate Affairs	Ottawa, Ont.
Standards Council of Canada	Ottawa, Ont.
Standards Council of Canada	Winnipeg, Man.
Supply & Services, Dept. of	Ottawa, Ont.

T

Tariff Board	Ottawa, Ont.
Trade and Commerce, Dept. of	Toronto, Ont.
Transport Canada	Ottawa, Ont.
Transport Canada - Aviation Safety Bureau	Ottawa, Ont.
Treasury Board of Canada	Ottawa, Ont.

U

US National Bureau of Standards	Washington, D.C.

W

Whiteshell Nuclear Research Est.	Pinawa, Man.

UNIVERSITIES & OTHER ORGANISATIONS

A

Alberta, University of	Edmonton, Alta.
Algonquin College	Ottawa, Ont.
American Foundrymen's Society	Buffalo, N.Y.
American Foundrymen's Society	Des Plaines, Ill.
American Foundrymen's Society	Trois Rivières, Que.
American Hot Dip Galvanizing Assoc.	New York, N.Y.
American Iron and Steel Institute (AISI)	New York, N.Y. Bethlehem, Pa.
American Society for Metals	Metals Park, Ohio
American Society for Metals	St. Louis, Miss.
American Society for Testing Materials	Philadelphia, Pa.
American Welding Society	Miami, Fla.
Arizona State Univ.	Tempe, Arizona
Argonne National Laboratory	Chicago, Ill.
Asbestos Institute	Montreal, Que.
Auburn Univ.	Auburn, Alabama

B

BC Hydro	Vancouver, B.C.
BC Research Council	Vancouver, B.C.
Bedford Institute	Halifax, N.S.
British Columbia, University of	Vancouver, B.C.
Brigham Young Univ.	Provo, Utah
Bureau de recherches géologiques et minières	Paris, France
Bureau National d'Études et de Recherche Aerospatiales	Paris, France

C

CAD/CAM	Cambridge, Ont.
Cambridge, University of	Cambridge, U.K.
Canadian Copper and Brass Development Assoc.	Toronto, Ont.
Canadian Electrical Association	Montreal, Que.
Canadian Institute of Guided Ground Transport	Kingston, Ont.
Canadian Institute for Metalworking	Hamilton, Ont.
Canadian Standards Association	Toronto, Ont.
Canadian Petroleum Association	Calgary, Alta.
Canadian Welding Bureau	Toronto, Ont.
Cape Breton Development Corp.	Cape Breton, N.S.
Carleton University	Ottawa, Ont.
CEGEP	Trois Rivères, Que.
Centre de Recherches Industrielles de Québec (CRIQ)	St. Foy, Que.
Central Electricity Generating Board	Gravesend, U.K.
Centre for Frontier Engineering Research	Edmonton, Alta.
Clarkson College	Potsdam, N.Y.
Concordia University	Montreal, Que.
CSIRA	Burlington, Ont.
CSNDT	Hamilton, Ont.

D

Dar Es Salaam, University of	Dar es Salaam, Tanzania
David Taylor Naval R & D Centre	Annapolis, Md.
Delft University of Technology	Delft, Netherlands
Dept. of Energy	Washington, DC

E

Ecole Polytechnique	Montreal, Que.
Ecole National Superieur des Arts et Metiers	Paris, France
Electric Power Research Institute	Palo Alta, Ca.
Energy, Dept. of	London, U.K.
European Coal and Steel Community (EEC)	Brussels, Belgium

G

Gansu Univ. of Tech. China	Lanzhon, P.R. of
Grey Iron Research Unit	Columbus, Ohio
Government of India Reactor Research Centre	Tamil Nadu, India

H

Hiroshima University	Hiroshima, Japan

I

INRS, Engerie	Varennes, Que.
Instit de Recherche de la Sidérurgie Française	St. Germaine en Laye, France
Institute for Atomic Energy	China
Institute for Research and Development	Haita, Israel
International Atomic Energy Agency (IAEA)	Vienna, Austria
International Copper Research Assoc.	New York, N.Y.
IREQ	Varennes, Que.
International Lead-Zinc Research Organization	New York, N.Y.
Iron and Steel Institute of Japan	Japan

J

Japan Society for Tech. of Plasticity	Tokyo, Japan

K

Kawasaki Steel Corp.	Chiba, Japan
Korrosionscentralen ATV	Glostrup, Denmark

L

Laval University	Quebec City, Que.
Lehigh University	Bethlehem, Pa.
Lawrence Berkely Lab.	Berkeley, Ca.
London University - Imperial College	London, U.K.

M

MNACC	Toronto, Ont.
Manchester University	Manchester, U.K.
Manitoba Research Council	Winnipeg, Man.
Massachussets Institute of Technology (MIT)	Cambridge, Mass.
McGill University	Montreal, Que.
McMaster University	Hamilton, Ont.
Memorial University	St. John's, Nfld.
Mohawk College	Hamilton, Ont.
Montreal University	Montreal, Que.

N

National Association of Corrosion Engineers	Houston, Tx.
National Coal Board - Coal Research Estab.	U.K.
National Bureau of Standards Research Lab.	Washington, D.C.
New Brunswick, University of	Fredericton, N.B.
Northern College	Kirkland Lake, Alta.
Nova Scotia Power Corp.	Halifax, N.S.

O

Oakridge National Laboratory	Oakridge, Ca.
Ontario Hydro	Toronto, Ont.
Ontario Ministry of Northern Development and Mining	Toronto, Ont.
Ontario Research Foundation	Mississauga, Ont.
Ottawa, University of	Ottawa, Ont.

P

Paris (University of)	Paris, France
Peking Institute of Metallurgy	Peking, China
Penn State University	State College, Pa.
Pulp and Paper Research Institute of Canada	Montreal, Que.

Q

Queen's University	Kingston, Ont.
Quebec Hydro	Quebec City, Que.
QIT-FER et Titane Inc.	Montreal, Que.
Queensland Water Commission	Australia

R

Research & Productivity Council of New Brunswick	Fredericton, N.B.
Royal Institute of Technology	Stockholm, Sweden
Royal Military College	Kingston, Ont.

S

Sandia National Laboratories	Albuquerque, New Mexico
Sandia National Laboratories	Livermore, CA
Saskatchewan Research Council	Saskatoon, Sask.
Singapore Institute of Standards and Industrial Research	Singapore
Stuttgart, University of	Stuttgart, W. Germany
Swedish Institute for Metals Research	Stockholm, Sweden

T

Technical Research Centre	Finland
Technical University of Nova Scotia	Halifax, N.S.
Toronto, University of	Toronto, Ont.
Trinity College	Dublin, Ireland

U

United Nations (UNIDO)	Latin America
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Université de Sherbrooke	Sherbrooke, Que.
University of Bristol	Bristol, England
University of Zambia	Lusaka, Zambia
U.K. Atomic Energy Authority	London, U.K.
U.S. Bureau of Mines Oregon	Minneapolis, Minn.
U.S. Naval Research Lab.	Washinton, DC.
U.S. Steel Research Lab.	Munroeville, Pa.

V

Virginia State University	Virginia, USA

W

Waterloo, University of	Waterloo, Ont.
Western Ontario, University of	London, Ont.
Windsor, University of	Windsor, Ont.
Winnipeg, City Waterworks	Winnipeg, Man.
Welding Institute (The)	Abington, U.K.
Welding Institute of Canada	Oakville, Ont.
Wollongong, University of	Wollongong, Australia

Y

Yale University	USA

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Commission XIII, Fatigue Testing Committee	(member)	O. Vosikovsky
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	(session chairman)	G. Carpenter
37TH CANADIAN METAL PHYSICS CONFERENCE 1987		
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G.R. Hoey	B.Sc., M.Sc., Ph.D. (Toronto)	Res. Sci.
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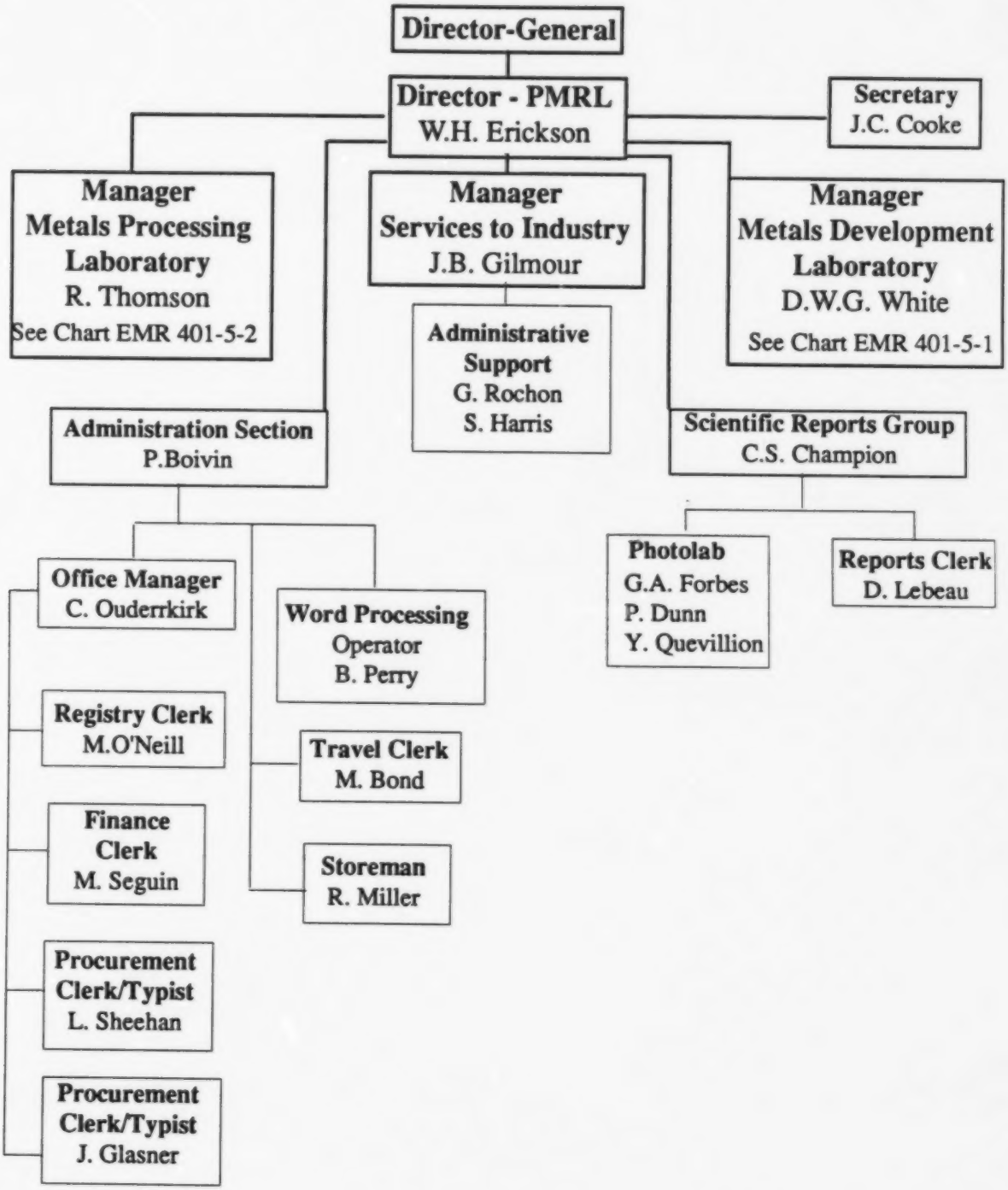

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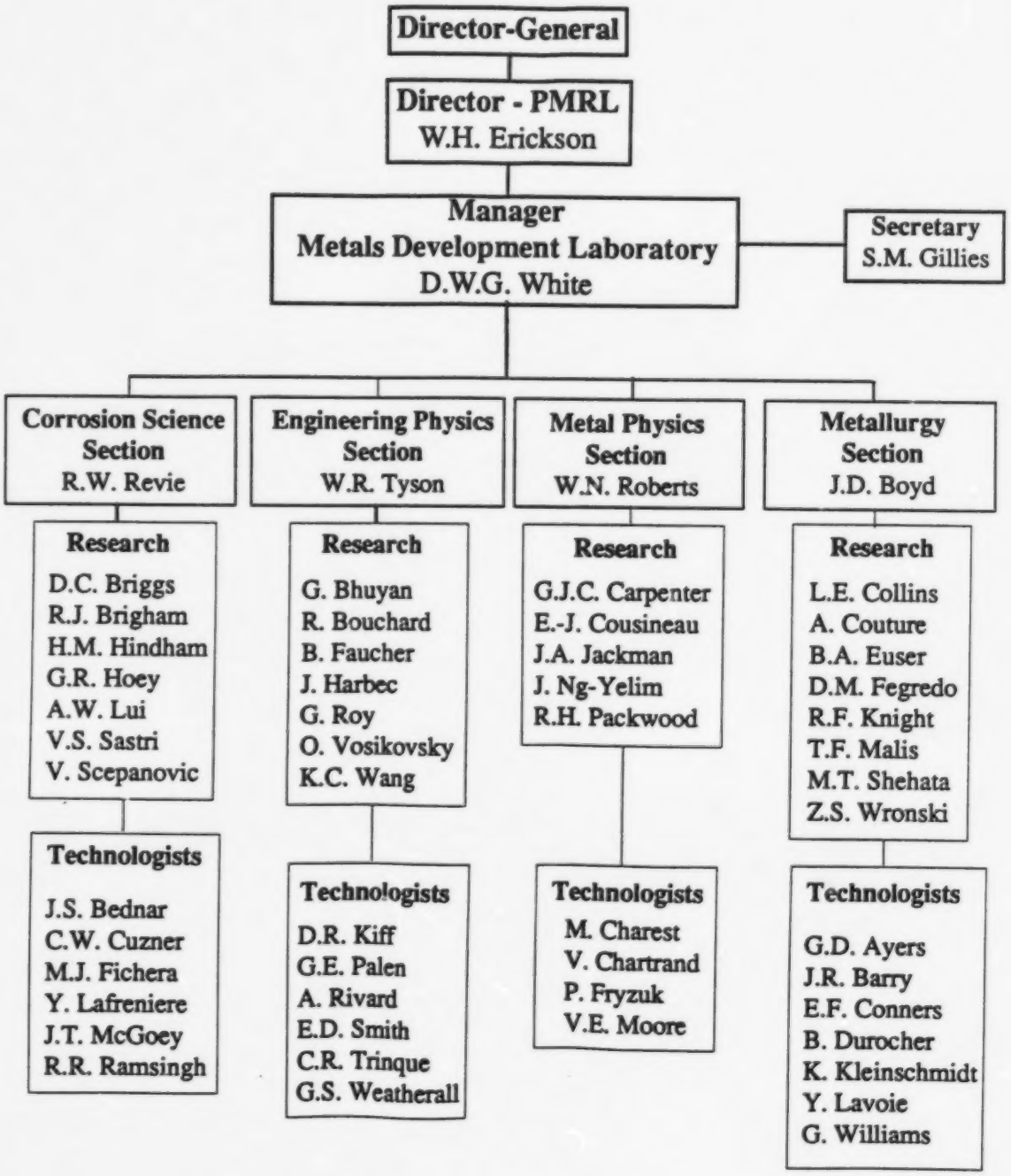
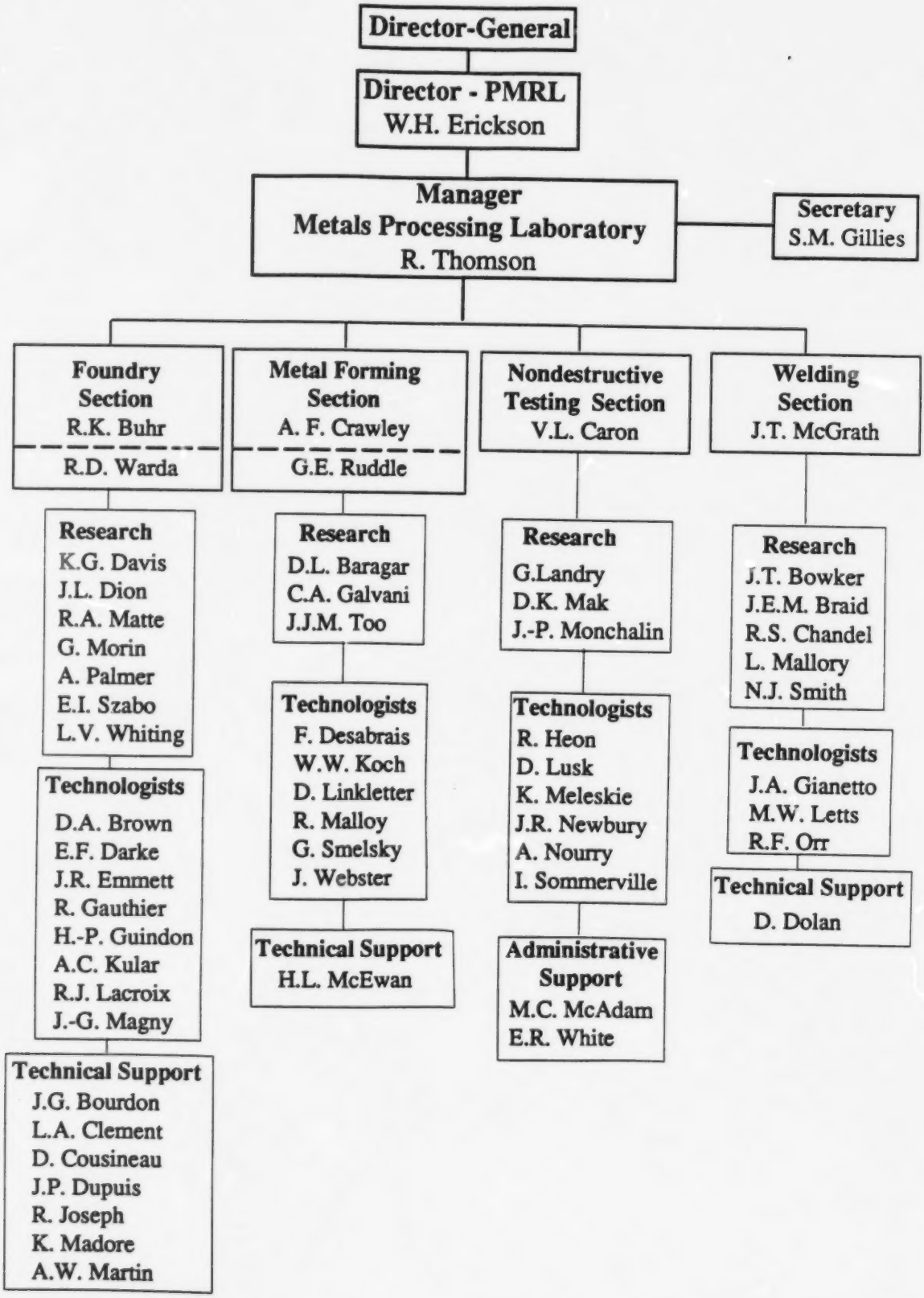
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